Volume 70
Number 2

June, 1956
Pages 111-234

$4.00 a Year
$1.25 a Number

Journal of the New England Water Works Association

ISSUED QUARTERLY
March, June, September and December

Published by
NEW ENGLAND WATER WORKS ASSOCIATION
73 Tremont Street, Boston 8, Massachusetts

Second-Class Mail Privileges Authorized at Boston, Mass.

Copyright, 1956, by the New England Water Works Association

OFFICERS
OF THE
New England Water Works Association
1955 - 1956

PRESIDENT

ALLAN F. MCALARY, Superintendent and Treasurer, Camden & Rockland Water Company, Rockland, Maine.
(Term expires September 1956)

VICE PRESIDENTS

EDWARD L. TRACY, Director, Division of Sanitary Engineering, State Department of Health, Burlington, Vermont.
(Term expires September 1956)

GEORGE G. BOGREN, Partner, Weston and Sampson, Boston, Mass.
(Term expires September 1957)

DIRECTORS

FRED P. STRADLING, Manager, Bristol County Water Company, Bristol, Rhode Island.
(Term expires September 1956)

CLARENCE L. AHLGREN, Assistant Superintendent, Water Works, Manchester, New Hampshire.
(Term expires September 1957)

WARREN A. GREYNER, Deputy Manager and Chief Engineer, Water Bureau of the Metropolitan District, Hartford, Connecticut.
(Term expires September 1958)

PAST PRESIDENTS

WILLIAM B. DUFFY, Superintendent of Public Works, North Andover, Mass.
ROGER G. OAKMAN, Superintendent, Water Division, Needham, Mass.

SECRETARY

JOSEPH C. KNOX, Secretary, New England Interstate Water Pollution Control Commission, Boston, Mass.

TREASURER

WILLIAM P. MELLEY, Commissioner, Water Department, Milton, Mass.

EDITOR

GEORGE C. HOUSER, 220 Clyde Street, Brookline 67, Mass.

THE Association was organized in Boston, Mass., on June 21, 1882, with the object of providing its members with means of social intercourse and for the exchange of knowledge pertaining to the construction and management of water works. From an original membership of only TWENTY-SEVEN, its growth has prospered until now it includes the names of over 900 men. Its membership is divided into six classes, viz.:

A Member shall be an officer or employee of a public or private water works, an engineer, chemist or other person qualified to aid or interested in the advancement of knowledge relative to water works.

An Honorary Member shall be a person of acknowledged eminence in some branch of water supply or of engineering.

A Junior shall be not less than eighteen years nor more than twenty-five years of age, a student or connected with water supply work.

An Associate shall be either a person, firm or corporation engaged in manufacturing or furnishing materials or supplies for the construction or maintenance of water works.

A Corporate Member shall be either a Water Board, Commission, Company or Municipal Corporation.

The initiation fees and annual dues are as follows:

Initiation Fees		*Annual Dues*	
Members	$ 2.00	Members	$ 4.00
Juniors	1.00	Juniors	2.00
Associates	10.00	Associates	20.00
Corporate Members	10.00	Corporate Members	20.00

This Association has at least eight regular meetings each year, of which five are held in Boston, one in northern New England, one in southern New England, and one, the annual convention, held in September or October on such date as the Executive Committee may designate.

SECOND BEST!

Only when the perfect pipe is invented.

The dream pipe for which all engineers pray would be light as a feather, indestructible, pliable enough to bend around obstructions, and would be installed by a magical machine that digs the trench and extrudes, lays and backfills the pipe.

Needless to say, this will be in the far distant future. Until such a dream pipe is invented, water works officials and engineers are specifying the next best pipe— LOCK JOINT CONCRETE PRESSURE PIPE It comes the closest to realizing their ideal specifications: long life at top carrying capacity because it never corrodes nor tuberculates; great strength to withstand internal pressure and exterior loading; versatility to meet the most difficult laying conditions, and minimum maintenance requirements over the years.

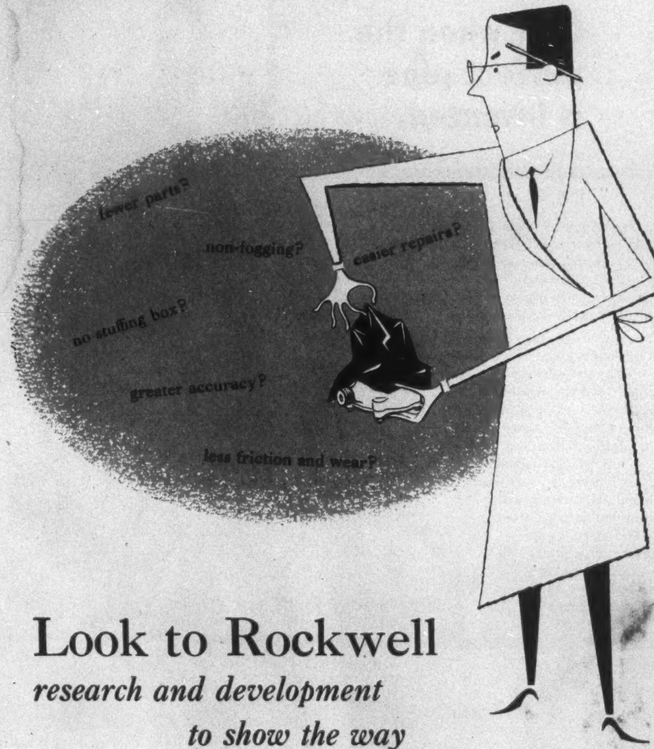
LOCK JOINT PIPE CO.

East Orange, New Jersey

Sales Offices: Chicago, Ill. • Columbia, S. C. • Denver, Col. • Detroit, Mich. • Hartford, Conn. • Kansas City, Mo

Pressure • Water • Sewer • REINFORCED CONCRETE PIPE • Culvert • Subaqueous

What do you want
in the meter of tomorrow?


fewer parts?
non-fogging?
easier repairs?
no stuffing box?
greater accuracy?
less friction and wear?

Look to Rockwell
research and development
to show the way

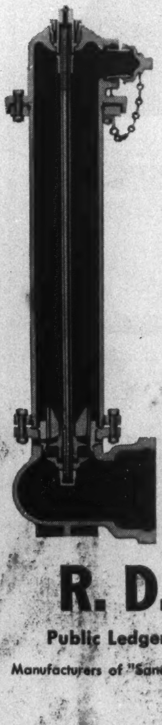
ROCKWELL r

Rockwell Manufacturing Company
Pittsburgh 8, Pennsylvania

HIGH QUALITY HYDRANT AT LOWEST COST

The R. D. Wood Standard Swivel Joint Hydrant with or without breakable flange and stem coupling

The R. D. Wood Standard Swivel Joint Hydrant is designed to provide maximum strength and reliability at lowest possible cost. Internal friction, which can lower pressure, is reduced to the minimum, well below A.W.W.A. specifications. Changes of diameter are carefully rounded and nozzleways are scientifically tapered.

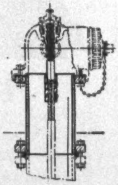


All Bronze Stuffing Box

Sound and simple in construction. It cannot rust or corrode. Hydrant operating thread can be greased or oiled by unscrewing one small plug.

Extension Piece

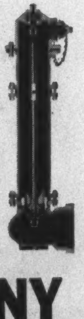
Can be inserted between hydrant head and barrel or between barrel and elbow. Installation does not require shutting off water supply.



Breakable Flange and Stem Coupling

Available at slight additional cost are this specially designed flange in the standpipe and a frangible coupling in the hydrant stem. A heavy blow that would ordinarily break the hydrant will snap the ring in the flange and the coupling in the stem. Both can be replaced quickly and inexpensively. No digging is necessary.

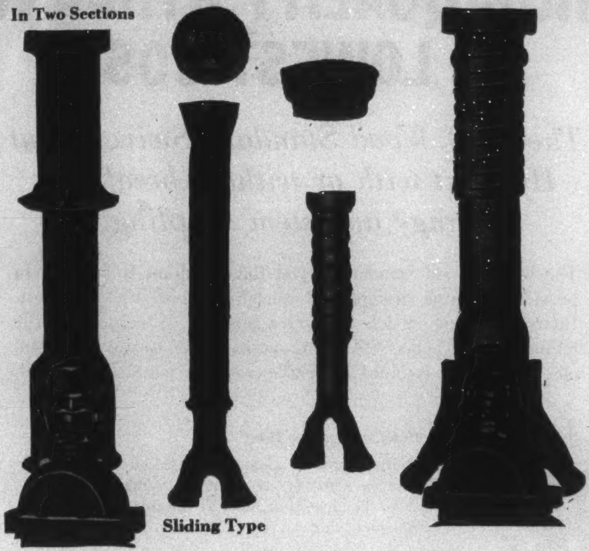
Available with standard types of pipe connections—bell, *mechanical joint*, flange, universal or screw.



R. D. WOOD COMPANY

Public Ledger Building, Independence Square, Philadelphia 5, Pa.

Manufacturers of "Sand-Spun" Pipe (centrifugally cast in sand molds) and R. D. Wood Gate Valves


In Two Sections
Sliding Type

The Three "Bigs" in Buying

1. *Standardization*
2. *Dependability*
3. *Quick Delivery*

ESTABLISHED 1849

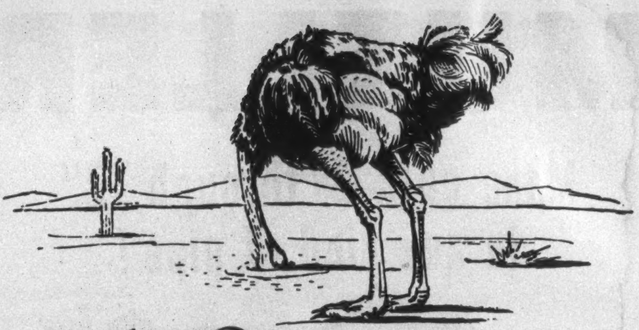
B AND T

BINGHAM & TAYLOR

CORPORATION

Genuine Buffalo Cast Iron
Service. Valve. Roadway and Meter Boxes
Manhole Frames and Covers

CULPEPER, VIRGINIA

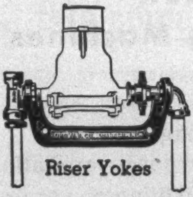


An Ostrich **is an**

EXPENSIVE METER MAN

And so is anyone else who must stand on his head to set or change a meter. Old fashioned, hard-to-get-at connections, outdoors or in the basement, are time consuming and costly. Not only is the meter hard to change, but periodic efficiency checks are neglected and water revenues are lost due to inaccurate meters.

Be sure your system is modern. See that Ford Meter-setting Yokes are keeping every meter available for quick changing and testing. Savings in time, and increased water revenues are often enormous.



Riser Yokes

Angle Yokes

Straight Line Yokes

You can change a meter

in a Ford Yoke

EASILY

There are models for every condition. Send for free catalog.

FORD

FOR BETTER WATER SERVICES

THE FORD METER BOX COMPANY, INC. Wabash, Indiana

MUELLER®

Make cuts 2" through 12" in any kind of pipe!

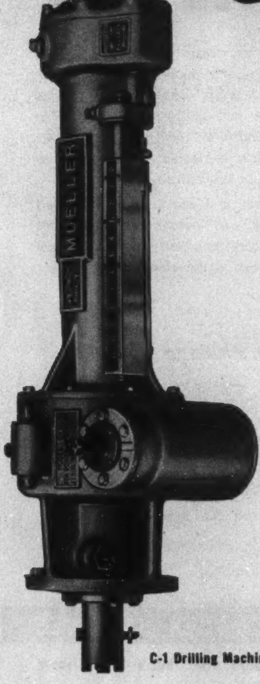
CC Drilling Machine

MUELLER Drilling Machines offer:

- 25" Boring bar travel
- Hand or power operation
- Air or gasoline power units
- Automatic or manual feed
- Standard feed indicator
- Pressures to 500 p.s.i. at 100° F.
- Temperatures to 500° F. at 250 p.s.i.

Install control valves, connect branch mains and make other water works installations – all under pressure.

Contact your Mueller Representative or write direct for complete information.



C-1 Drilling Machine

MUELLER CO.
Dependable Since 1857
MAIN OFFICE & FACTORY · DECATUR, ILLINOIS

Wide World Photo

this could happen in your town

THIS CITY STREET CAVED IN when a water main broke. It's a dramatic, but not an unusual example of what water does to road bedding.

Protect your roads and pipes from the problems of leakage by Centrilining. This patented process thoroughly cleans and centrifugally lines pipes with cement mortar. Leakage, tuberculation and interior corrosion are permanently checked . . . carrying capacity and distribution pressure are increased to "better than new" highs. And the whole process is done with pipes in place . . . no excavation . . . no traffic disruption.

With Centrilining you can save your water mains . . . and streets too.

Write today for free booklet

CEMENT-MORTAR LININGS FOR PIPES IN PLACE

3,500,000 FEET OF EXPERIENCE

CENTRILINE CORPORATION

A subsidiary of Raymond Concrete Pile Co.

140 CEDAR STREET, NEW YORK 6, N. Y.

Branch Offices in Principal Cities of United States and Latin America

Which uses the most water?

Filling Station — or Church Building?

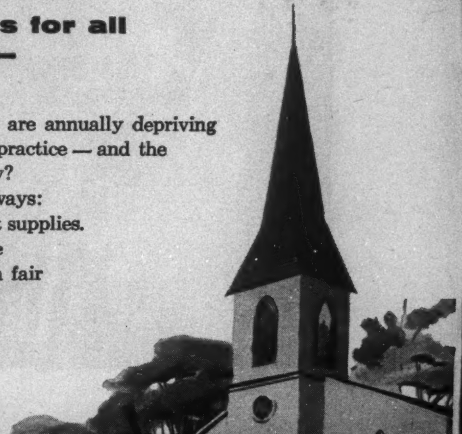
ANSWER: Before one Midwestern community installed water meters, gas stations were billed a flat rate of $12 per year; so were the churches. Last year, the average bill for all filling stations was $48, while in only one case did a church use more water than the minimum charge of $7.20.

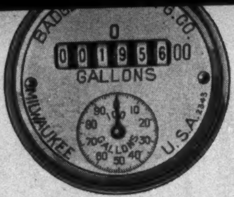
Badger water meters provide fair rates for all users – help conserve vital resources – key to the future of your community.

The above is a typical example of how flat-rate water policies are annually depriving water departments of thousands of dollars of revenue. Is this practice — and the *water waste* that goes with it — a problem in your community?

Studies show Badger meters serve vital water needs many ways: (1) Each customer becomes a self-interested guardian of present supplies. (2) A fair allotment of available water is assured. (3) Users are charged for exact amounts used. (4) Water departments get a fair price for water and service. And, (5) greater efficiency helps keep water departments self-supporting.

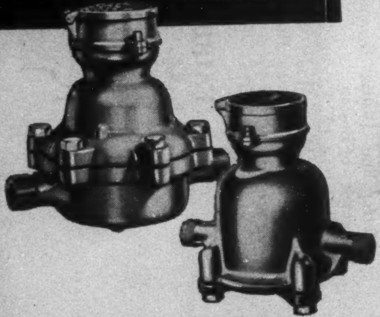
Water is vital to industrial, business and residential development. Make certain you act NOW to safeguard your community's future — specify Badger water meters.





Sensitive registering key to maximum revenue per installation

One of the greatest "business machines" your community can own. Badger water meters are always on duty. Dial accurately registers all flow from the smallest stream to maximum meter capacity. Service records also prove the dependability of Badger meters . . . show why waterworks men agree, "It pays to install Badger meters."



For complete details on how Badger meters can help your community save water, work and money, write us.

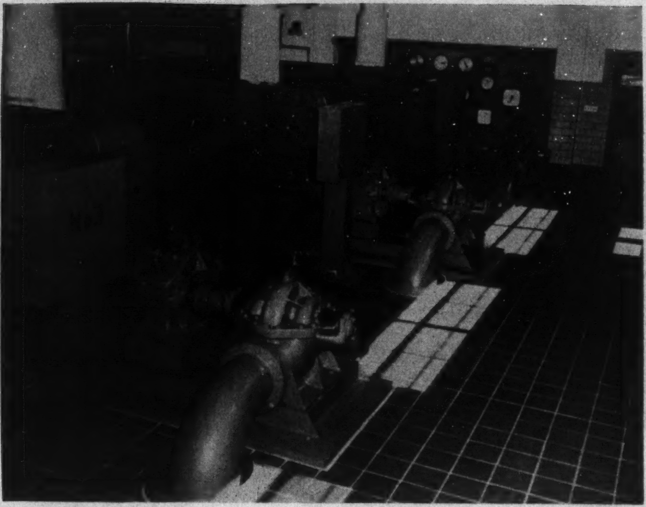
Badger Water Meters

BADGER METER MFG. CO. • MILWAUKEE 45, WISCONSIN

Water is Vital

"Badger Meters have conserved it for 50 years"

ANOTHER
FAIRBANKS-MORSE
LEADER



F-M Equipment at the New M.D.C. Newton Street Pumping Station, Brookline

The three Fairbanks, Morse Diesel Engine Driven Pumps pictured above are capable of delivering 4.10 Mgd under present operating conditions into the system of the M.D.C. and the town of Brookline.

Under future conditions, following completion of the Commission's proposed water system lines, the pumps will deliver water at the rate of 5.10 Mgd into the M.D.C.'s Southern Extra-High service lines and into the Bellevue Hill Reservoir.

The design and supervision of this new station for the Water Division of the Metropolitan District Commission was by Coffin & Richardson, consulting engineers of Boston.

The 10″ x 12″ Fairbanks, Morse Figure 5813 Pumps are each driven by a Fairbanks, Morse Model 31A6¼ Diesel Engine.

A trained Fairbanks, Morse Engineer is on hand to help solve YOUR pumping problems.

Write or telephone to:

FAIRBANKS, MORSE & CO.

178 Atlantic Avenue **Boston 10, Massachusetts**

Telephone: LAfayette 3-3600

METERS
FEEDERS
CONTROLS

PROPORTIONEERS, INC.

Proportioning Pumps and Controls   Diatomite Filters

OMEGA MACHINE COMPANY

Volumetric and Gravimetric Feeders for Dry and Fluid Materials.

BUILDERS-PROVIDENCE, INC.

The Venturi Meter • Instruments for Recording, Indicating, and Controlling Flow, Liquid Level, Pressure and Weight • Chlorinizers • Chlorine Gas Feeders • Butterfly Valves.

B-I-F Industries, Inc. offers the combined experience and equipment of these three major suppliers of meters, feeders, and controls . . . for every problem in the water, sewage, and waste fields. For Bulletin B-I-F 6, a comprehensive description of our complete line, call or write: B-I-F Industries, Inc., 291 Washington Street, Islington, Massachusetts. Tel: DEdham 3-5690.

B-I-F INDUSTRIES
PROVIDENCE, RHODE ISLAND

METERS
FEEDERS
CONTROLS

CITY OF BROCKTON — SILVER LAKE STATION

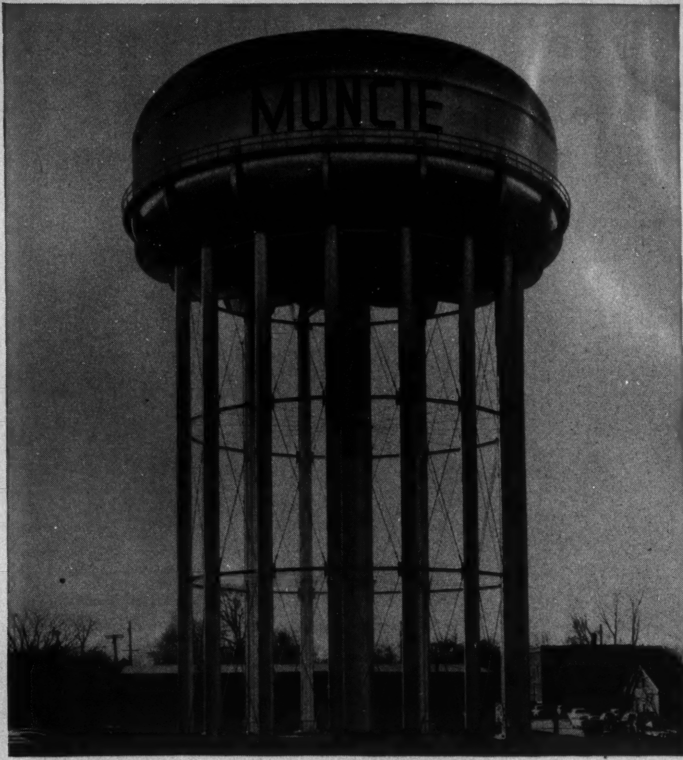
Shown above are two 400 HP motor driven pumping sets each consisting of two single stage pumps in series with overhead cross-over piping. The unit design conditions are 4500 G.P.M. against 300 Ft. T.D.H. The firm of Hayden, Harding and Buchanan prepared the plans and specifications and supervised the installation of all the equipment.

TURBINE EQUIPMENT COMPANY OF NEW ENGLAND

80 Federal Street **Phone LIberty 2-5993** **Boston 10, Mass.**

New England Representatives for

DE LAVAL STEAM TURBINE COMPANY
TRENTON, NEW JERSEY



MODERN WATER STORAGE...*since 1897*

This imposing 2,000,000 gallon PDM Radial Cone Elevated Steel Tank at Muncie, Indiana typifies the progress made in municipal water storage since the *first* elevated steel tank, built by Pittsburgh-Des Moines at Scranton, Iowa nearly sixty years ago (and serving well today).
May we quote on your requirements?

Write for our latest Elevated Tank Brochure

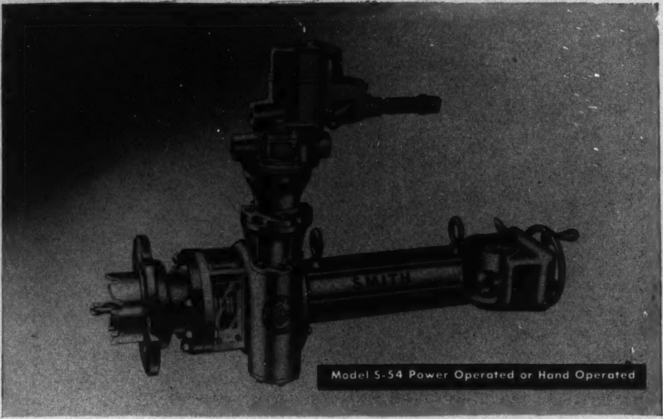
PITTSBURGH • DES MOINES STEEL CO.

Plants at PITTSBURGH, DES MOINES, SANTA CLARA, FRESNO, and CADIZ, SPAIN

Sales Offices at:

PITTSBURGH (25)..... 3424 Neville Island
NEWARK (2) ... 221 Industrial Office Bldg.
CHICAGO (3) 1228 First National Bank Bldg.
LOS ANGELES (48).... 6399 Wilshire Blvd.
DES MOINES (8)....... 925 Tuttle Street
DALLAS (1) .... 1229 Praetorian Building
SEATTLE .... 532 Lane Street
SANTA CLARA, CAL...... 631 Alviso Road
MADRID, SPAIN ... Diego DeLeon, 60

SMITH TAPPING MACHINES FOR TAPS 2″ THRU 12″ INCLUSIVE



Model S-54 Power Operated or Hand Operated

The NEW Smith S-54 Tapping Machine is the most modern, efficient and economical machine available. The Machine is used with Tapping Sleeves, Hat Flanges, Saddles and Tapping Valves to make 2″ through 12″ connections under pressure to Cast Iron, Cement-Asbestos, Steel and Reinforced Concrete Pressure pipe. Features: 1. Positive automatic feed insures correct drilling and tapping rate. 2. Travel is automatically terminated when tap is completed—cutter and shaft cannot overtravel. 3. Telescopic shaft reduces overall length. 4. Mechanism is housed in heat treated Aluminum Case filled with lubricant. 5. Stuffing Box and Packing Gland is accessible without disassembling machine. Line pressure cannot enter machine case. 6. Extra large diameter telescopic shaft add strength and rigidity. Timken radial—thrust bearings maintain alignment, reduce friction and wear. 7. Worm gearing operates in lubricant, torque is reduced to the minimum. 8. Cutters have replaceable Flat and Semi-V alternate teeth of High Speed Steel or Tungsten Carbide. 9. Flexibility: Hand Operated Machines can be converted to Power Operation by interchanging worm gearing. Bulletin T54 sent on request.

FIRE HYDRANTS · VALVES · SINCE 1896

THE A.P. SMITH MFG. CO.

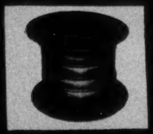
EAST ORANGE . NEW JERSEY

THE NATION'S No. 1 SOURCE

for dependable pipe line equipment

Like hundreds of Pollard customers, you'll find it mighty pleasant and convenient to order pipe line equipment from Pollard.

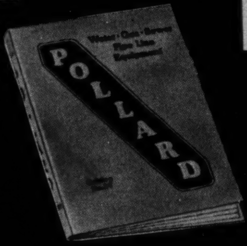
Here, under one roof and listed in one comprehensive catalog, are all the time and money saving products you need on the job. Each is guaranteed for dependability, economy. Each is backed by Pollard service.

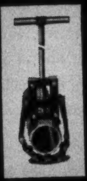


MANHOLE CUSHION

DIAPHRAGM PUMPS

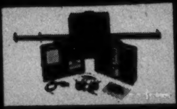
JOINT RUNNER



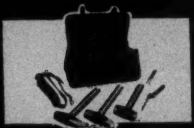


PIPE CUTTER

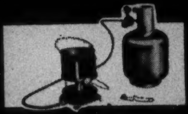
MAKE POLLARD YOUR SOURCE FOR PIPE LINE EQUIPMENT. ORDER FROM POLLARD CATALOG 26.



M-SCOPE PIPE FINDER



CALKING TOOLS



MELTING FURNACE

PIPE LINE EQUIPMENT

JOSEPH G.
POLLARD
CO., INC.

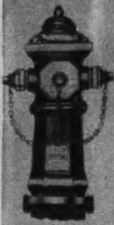
PIPE LINE EQUIPMENT

Place your next order with POLLARD

If it's from POLLARD . . . It's the Best in Pipe Line Equipment

NEW HYDE PARK · NEW YORK

Branch Offices: **1064 Peoples Gas Building, Chicago, Illinois**
333 Candler Building, Atlanta, Georgia



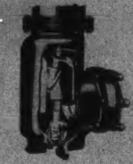
LIST
90-0

LIST
75-0

O.S. & Y VALVE

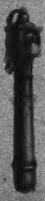
NRS VALVE

GEARED VALVE



FIRE HYDRANTS

FLOOR STAND



INDICATOR

THE MARKET PLACE FOR QUALITY VALVES

The consolidation of two great valve companies with a combined experience of more than 165 years devoted primarily to the manufacture of water works valves and hydrants now provides the most extensive market place in the industry.

A.W.W.A. VALVES AND HYDRANTS: with several types of each to choose from with a complete line of valve ends in every size required and backed by the combined engineering, manufacturing and application resources of both companies.

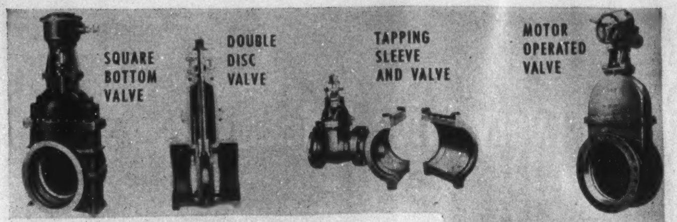
LARGE AND SPECIAL VALVES FOR LOW AND HIGH PRESSURE SERVICE: up to 72″, fabricated with the most modern foundry and machine shop equipment, recently expanded.

SQUARE BOTTOM VALVES: from 4 to 48″, designed and built to stand up under the severe conditions of automatic operation, throttling and constant opening and closing.

THE LUDLOW VALVE MFG. CO., INC. TROY, N.Y.

TRADE
LUDLOW
MARK

GATE VALVES • FIRE HYDRANTS • SQUARE BOTTOM VALVES
CHECK VALVES • TAPPING SLEEVES • AIR RELEASE VALVES



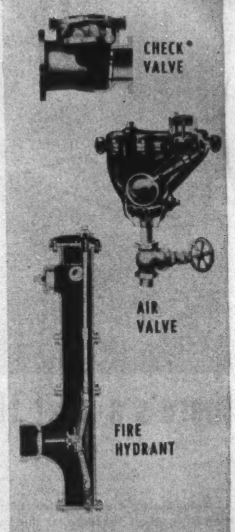
ACCESSORIES: Where experience counts most—the selection of by-passes, automatic, electric or hydraulic operation and countless highly special equipment for the pumping plant.

TAPPING SLEEVES AND VALVES: up to 48", that insure speed, safety and low costs when cutting valves into the lines.

CHECK VALVES: insure against slam on pump shutdowns. Clearway-quiet closing, single disc. Sizes up to 30" with or without lever arm and spring.

AIR VALVES: a combined air-and-vacuum and air release valve that allows air to escape when filling the lines and air to prevent vacuum when emptying. Also used on air tanks, booster bowls and turbine pump discharge.

SERVICE: The names Ludlow and Rensselaer mean the same today that they have during your lifetime. The desire to serve the Water Works Field in person—in research and design and in prompt delivery of original equipment and spare parts for all products has not changed. On the other hand, our ability to serve has at least doubled.



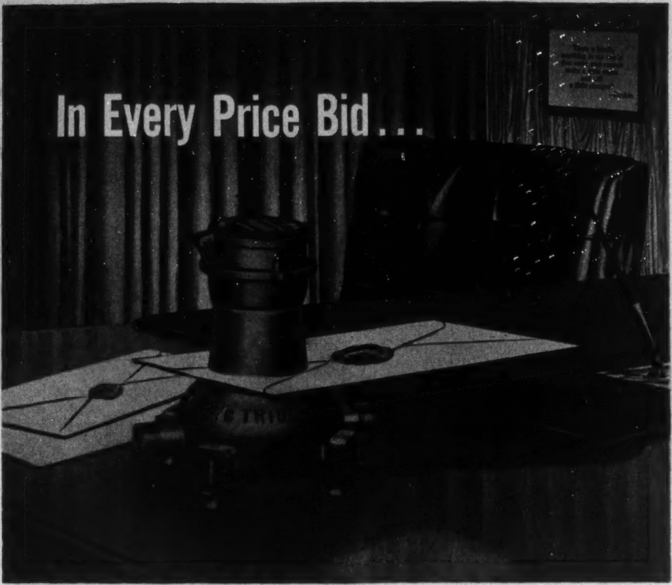
Bulletins available on all equipment, replacement parts and accessories.

Rensselaer
VALVE CO.

TROY, NEW YORK

DIVISION OF
THE LUDLOW VALVE
MANUFACTURING CO., INC.

GATE VALVES • FIRE HYDRANTS • SQUARE BOTTOM VALVES
CHECK VALVES • TAPPING SLEEVES • AIR RELEASE VALVES



there's a cost that stays *Sealed* for seven years

All water meters are fine instruments. Any fine instrument loses accuracy as it wears. Because of this fact, written between the lines of any water meter price are two items you can't read for many years. Yet they are vital in choosing the lowest "total price."

First, as a meter loses accuracy, it gives away revenue. Before its first overhaul it may give away twice as much money as it seems to save in its "low bid" original price.

Secondly, to keep the meter accurate you may have higher repair costs over the years . . . or premature scrap-and-replace costs. Good meters often vary widely in this respect.

Tridents are preferred because they earn more and cost less in the long run. They never become obsolete. You modernize your Tridents as you repair. Ask your neighbor . . . or ask Neptune for details.

NEPTUNE METER COMPANY

19 West 50th Street • New York 20, N. Y.

NEPTUNE METERS, LTD.

1430 Lakeshore Road • Toronto 14, Ontario

Branch Offices in Principal American and Canadian Cities

neptune

Table of Contents

PAGE

The Re-lining of Water Mains *in Situ*
By Alan Atkinson 111

Meeting Accelerated Industrial Demands in Springfield
By Peter C. Karalekas 163

An Approach to Water-Supply Toxicology
By Benjamin C. Nesin 172

Determination of Charges for Public Fire Protection
By Darrell A. Root and Thomas R. Camp
Discussion by Louis E. Ayres 199
Authors' Closing Discussion 207

Memoir of Arthur C. King 212

Memoir of Harry U. Fuller 214

Report of Committee on Rainfall and Yield of Drainage Areas—
Rainfall in New England:
Part IV. Rainfall in Vermont 216

Proceedings:
February 1956 Meeting 229
March 1956 Meeting 231

New England Water Works Association
ORGANIZED 1882

VOL. LXX JUNE, 1956 No. 2

This Association, as a body, is not responsible for the statements or opinions of any individual

THE RE-LINING OF WATER MAINS *IN SITU**

BY ALAN ATKINSON, M.Eng., M.I.C.E.

SYNOPSIS

The paper records that the difficulties arising from the progressive deterioration and the reduction in the carrying capacity of iron and steel water mains conveying soft or aggressive waters, which cause internal corrosion and encrustation, have now been overcome economically by reconditioning the mains *in situ.*

The several methods of scraping, cleaning and afterwards relining the mains with a protective lining and/or coating, which have proved feasible and economical, are described in detail. A short summary is given of the experiences and the opinions of the engineers in certain countries where they have been tried, as to the merits of the various processes, together with the author's observations and conclusions.

1. *Introduction*

This paper is concerned solely with the re-lining *in situ* of iron and steel underground pressure mains.

The major part of the paper was originally presented by the author in the form of a Special Report at the Amsterdam Congress of the International Water Supply Association in September, 1949, where it aroused great interest and provoked a useful discussion.

In a post-war era of greatly enhanced costs, the urgent need to effect economy wherever possible in the maintenance and operation of water undertakings has recently caused water engineers to direct increased attention to the possibility of reducing costs by the adoption of a policy of reconditioning water mains *in situ.*

In view of the importance of the subject and the wide interest shown, and in response to special requests, the author consented to present this revised paper for discussion at the 1950 Summer Meeting of the Institution, and to include additional recent experience in the scraping and re-lining of three large water mains forming part of the Manchester Thirlmere Aqueduct.

---

* At the Pavilion, Jephson Gardens, Royal Leamington Spa, 3rd May, 1950.

NOTE: This paper is reprinted from the *Journal of the Institution of Water Engineers* (London), Vol. IV, No. 4, July, 1950 (p. 293). The author was awarded the reciprocal diploma from the New England Water Works Association in May, 1955. Due to lack of space, it has been necessary to omit many of the figures contained in the original paper.

Iron and steel pipes for the conveyance of water under high pressure have gradually been developed during the last three centuries. Cast iron mains were used for water services at Versailles about the year 1664 and are reported to be still in service. In Great Britain cast iron water mains were used in Glasgow in 1765, and there are many mains in Great Britain over 100 years old, which are still in useful service for water supply.

2. *Corrosion of Iron and Steel*

(*a*) *General*

Unprotected iron and steel corrodes rapidly when exposed to water, damp atmosphere and soil, and engineers using these metals for water pipes were soon compelled to seek means of preventing the corrosion and the accompanying deterioration of the metal. Considerable research into the problems arising from corrosion has been undertaken, especially during the last 50 years, and in Great Britain at the present time a Research Committee of the Institution of Water Engineers is investigating the "Corrosion of Pipes", in collaboration with the Department of Scientific and Industrial Research.

Steel corrodes more rapidly than cast iron, and in consequence many engineers prefer to use cast iron rather than steel for water mains, although it is considerably weaker in tension and requires a greater thickness and weight of metal.

(*b*) *Chemical Aspect of the Corrosion of Iron and Steel Water Mains*

(Sections (b), (c) and (d) are for record only, and are not intended for discussion at this Meeting.)

Corrosion may be defined as the destruction of metals by chemical or electro-chemical agencies, in contrast to erosion, which is destruction by mechanical agencies.

Conditions which have a bearing on corrosion are varied and numerous. They include:—

Dissolved oxygen content of the water
Acidity
Degree of alkalinity or carbonate hardness
Presence of chlorides
Imperfect coatings
Accumulations of sediments or deposits
Electrical leakages
Dissimilar metals in contact
Bacteria.

Corrosion of iron and steel water mains is largely due to dissolved oxygen in the water. If bare iron is placed in a fully-aerated water, the whole surface of the iron is quickly covered with a film of hydrated oxide of iron and corrosion proceeds more or less uniformly. If conditions are such that a loose film of corrosion product, not in immediate contact with the metal, is formed, then corrosion will continue. If the film is dense and strongly adherent to the metal, however, then corrosion will be stifled and may cease.

If a part of the iron is prevented from receiving its full supply of oxygen, then that part becomes "anodic" and the fully-aerated part "cathodic", and small electrical currents will flow between these areas, through the iron and the surrounding water. Ferrous (iron) ions will be liberated into the water from the anodic area and alkali will be formed at the cathodic area and, when these products meet, hydrated oxide of iron is formed. Under quiescent or low flow conditions, the hydrated oxide of iron will be precipitated very close to the anodic area and so further restrict the supply of oxygen, and so the corrosion continues or increases. If the flow is sufficient to carry away these corrosion products, then ochry waters are formed. If the cathodic area is large compared with the anode, then the attack at the anode is intense and can lead to serious pitting, even to failure of the metal.

In general, the above conditions will occur in soft waters. In the case of hard waters, the alkali generated at the cathodic areas can react with the alkalinity or carbonate hardness of the water and precipitate calcium carbonate, so that dense adherent deposits in close contact with the metal are formed and the attack is stifled and may cease altogether. If, however, the hard water contains an excess of carbonic acid (or carbon dioxide), usually called "aggressive carbonic acid", then the precipitation of calcium carbonate will be prevented and corrosion will continue. Carbonic acid, of itself, is not highly corrosive to iron; its danger lies in the prevention of calcium carbonate precipitation.

Chlorides, if present in large amounts, lead to the intensification of corrosion, as they favour the formation of loose corrosion products which do not stifle attacks.

Particles of sediment or accumulations of deposits can give rise to corrosion attacks described above, as they prevent the free access of oxygen to the metal. Scratches in an oxide film or perforations in the coating of a main can become anodic areas of attack.

An acid water, by its nature, will produce more soluble corrosion products and these will not be able to prevent further corrosion as they are carried away by the water.

Electrical leakages (such as from tram-car rails) have caused very serious corrosion of water mains, both externally and internally. A 6-in. water main in Brooklyn, U.S.A., was found to carry 70 amps. during peak load periods on the nearby electric railway and serious destruction of water mains occurred in the district.

Sulphate-reducing bacteria, often so potent in external attack on mains, have also been detected in internal corrosion products as they may find conditions suitable for growth if sulphates are present in sufficient amounts. Iron bacteria, such as *Crenothrix,* have been found in many ferruginous deposits from mains. Whether or not bacteria actually cause corrosion of mains is not definitely established.

Dissimilar metals in contact can give rise to corrosion of one or the other of the metals, depending upon which becomes the anode. Corrosion in this case, however, is localized and does not lead to general corrosion of the mains.

(*c*) *Graphitic Deterioration of Cast Iron Mains*

When cast iron suffers general or localized corrosion, the metal appears superficially to be quite sound when the products of corrosion are removed. If it is scraped however, it will almost invariably be found to be quite soft and to consist essentially of graphite, the iron having been removed in the process of corrosion. This effect is known as "graphitic rotting or softening".

(*d*) *Tuberculation, or Nodular Encrustation*

As previously mentioned, anodic attack can be stifled if the corrosion products are dense and strongly adherent to the metal, or the attack may continue unabated if they do not remain in contact. An intermediate form of attack results in the formation of porous corrosion products in contact with the metal. As corrosion proceeds, the iron removed from the main is precipitated within the body of the deposit, chiefly as voluminous magnetic oxide of iron, and the surface in contact with the water is fully oxidized to hydrated ferric oxide. If the surface film of the incipient nodule is broken, further corrosion products are built up inside through the perforation, and a nodule or tubercle is formed.

Such nodules often contain chloride and sulphate ions greatly in excess of those found in the water flowing in the main, due to the migration of these ions to the anodic area under the influence of the small electrical potentials incidental to corrosion. Highly saline waters frequently produce this form of corrosion.

Tuberculation inevitably impedes the flow of water and small-diameter mains frequently become completely blocked, as the volume of corrosion so formed is five or six times that of the iron destroyed. The addition of alkali usually arrests or reduces this form of attack, except in the case of highly saline waters.

Sulphate-reducing bacteria and iron bacteria such as *Crenothrix* are often found in these tubercles, and some authorities claim that they are the primary cause of this form of corrosion. Chlorine may be used to suppress these bacteria.

3. *Modern Methods of Protection against Corrosion—Pipe Linings*

Vertically cast iron pipes and spun iron pipes.—Chiefly Dr. Angus Smith's tar base solution, which is cheap and reasonably satisfactory if the pipes are twice dipped at a temperature of 300° to 350°C.

More recently, bituminous enamels, and "thick" and "thin" linings of centrifugally-applied bitumen, have proved to be quite satisfactory.

Cement or concrete lining applied centrifugally, with or without dipping in Angus Smith's solution after lining (which provides additional protection and reduces friction losses), has been found to give excellent protection.

Steel pipes.—Angus Smith's solution generally affords but slight protection. "Thick" or "thin" linings of centrifugally-applied bitumen with external asphalt sheathing are much used, especially for very large diameters.

Cement and concrete lining applied centrifugally either with asphaltic external sheathing or surrounded externally with a minimum of 4 in. of concrete after laying in the pipe trench, provides excellent protection.

Small pipes only.—Glass lining; but this is not considered to be a practical method for large sizes.

Plastic linings should be possible, but up to the present none has been so employed.

4. *Tuberculation and Encrustation—The Cause of Reduced Carrying Capacity*

When used for conveying certain types of soft water, cast iron mains protected by Dr. Angus Smith's coating suffer a decrease in carrying capacity with advancing age which is caused by progressive tuberculation and encrustation.

Factors affecting the amount of reduction of carrying capacity are: the chemical characteristics of the water; velocity; the quality of the metal; and the degree of protection afforded by various linings. Flushing is of little practical value as a preventive.

Encrustation causes great reduction in volume and pressure, chokes ferrules, and gives rise to many complaints of inadequate supply and dirty water.

Steel mains are found to behave in a somewhat similar manner to those of cast iron but they usually deteriorate much more quickly. With steel mains, nodular encrustation sets up severe pitting and grooving with subsequent perforation and rapid erosion when once water commences to escape. (See Figs. 1A, 1B, 2A, 2B and 2C.)

5. *Encrusted Trunk Mains and Reticulation Systems*

Whilst water undertakings supplying soft water now have suitably lined pipes or asbestos-cement pipes for new mains, they continue to be embarrassed by having to maintain an efficient day-to-day water serv-

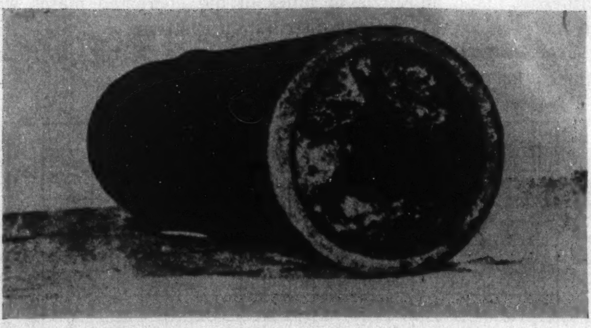


Fig. 1A.—A Typical Example of Encrustation of a 4-in. Unlined Cast Iron Water Main.

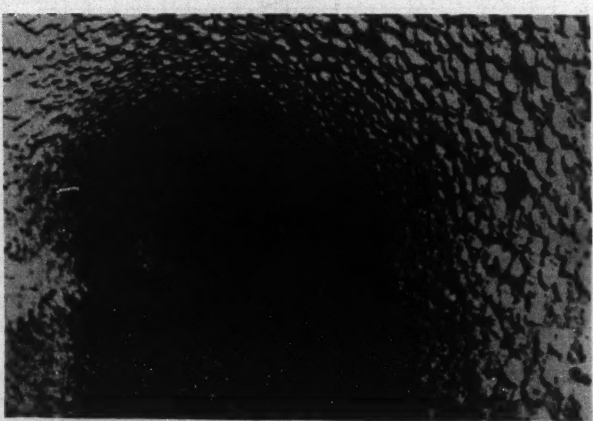


Fig. 1B.—Encrustation (Jan., 1950) of a 36-in. Unlined Cast Iron Main (Thirlmere Aqueduct) Laid in 1894.

ice through many hundreds of miles of old encrusted mains which form the greater part of their distribution systems.

Previously the only methods of remedying the distribution troubles arising from encrusted mains were:—

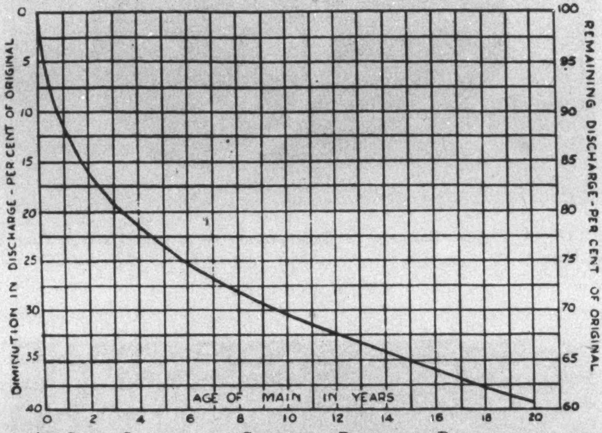


FIG. 2A.—CHART SHOWING THE CALCULATED PERCENTAGE DIMINUTION IN THE DELIVERY CAPACITY OF UNLINED LARGE-DIAMETER CAST IRON MAINS (A. A. Barnes)

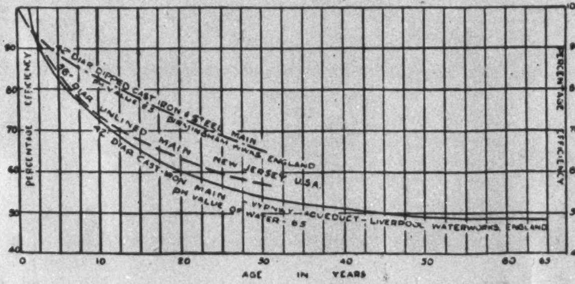


FIG. 2B.—CHART SHOWING THE PERCENTAGE DIMINUTION IN THE DELIVERY CAPACITY OF LARGE MAINS.

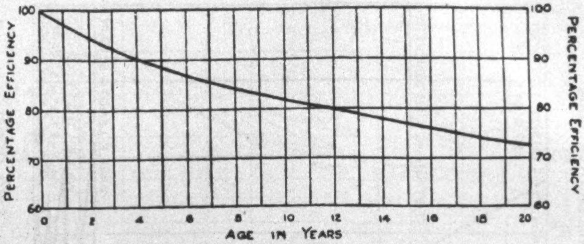


FIG. 2C.—CHART SHOWING THE PERCENTAGE DIMINUTION IN THE DELIVERY CAPACITY OF A 27-IN. CAST IRON MAIN, HODDER AQUEDUCT, FYLDE WATERWORKS.

(i) scraping without re-coating or re-lining—with attendant disadvantages; or

(ii) laying new mains to replace the old encrusted mains—a considerable expense.

(*a*) *Scraping*

The obvious and now well-established method of restoring the carrying capacity of mains is the removal by scraping of all encrustation and nodules down to the original surface, and such means have been used in Great Britain since before the year 1866. The capacity is usually restored to about 80 to 90 per cent of the original new main; but it is soon found that, after scraping, encrustation and reduction in carrying capacity proceed again at a greater rate than before, so that a further scraping becomes necessary in a comparatively short time. Additionally, there is usually an anxious period of discoloured water due to "bleeding" of the main after putting it back into service, as bare metal is left exposed. Consequently, it is considered that, except for calcareous deposits, pipe scraping without re-lining is of little value save as a temporary expedient. (See Figs. 3A, 3B and 3C.)

(*b*) *The Need for the Reconditioning of Mains*

The solution of the problem of the reconditioning, by cleaning and re-lining, of encrusted mains in cases where the metal is reasonably sound, is therefore of great practical importance. Considerable attention and experiment have been devoted to the problem in Australia,

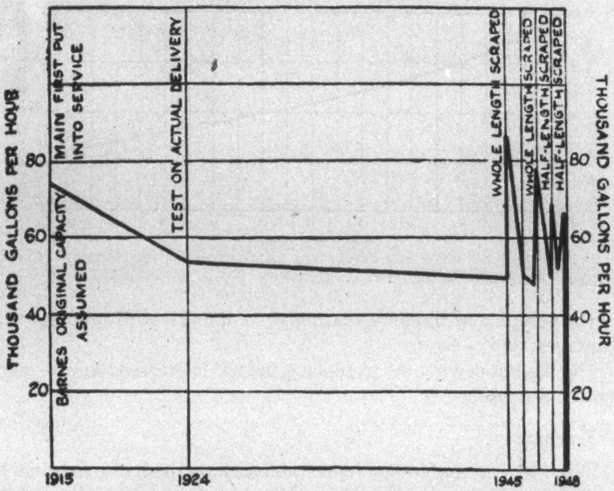


Fig. 3A.—Chart Showing the Reduction in Delivery Capacity of the 12-in. Cast Iron Main from Sheffield to Rotherham, and the Effect of Three Times Scraping —1915 to 1948.

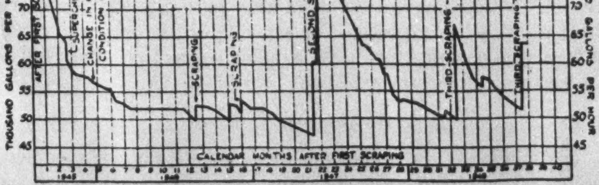


Fig. 3B.—Chart Showing the Variation in Delivery Capacity of the Same Main after Each Scraping, and the Subsequent Rapid Deterioration—August, 1945, to September, 1948.

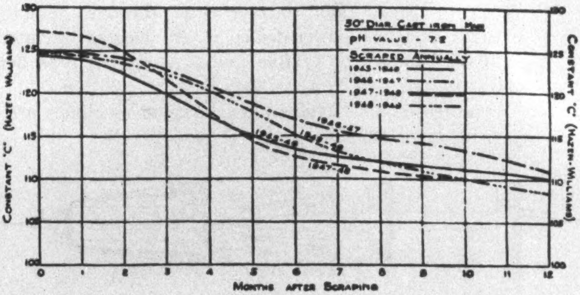


Fig. 3C.—Chart Showing the Depreciation of Flow after Scraping: 30-in. Cast Iron Main, Newcastle and Gateshead Waterworks.

Great Britain and the U.S.A. during the last 20 to 25 years, and a fair degree of success has been achieved, depending upon the method employed.

(*c*) *Methods of Scraping Mains* in situ

As the removal of all encrustation and nodules is an essential preliminary to all methods of re-lining water mains *in situ*, it is desirable to describe very briefly the various methods of scraping which have been employed successfully.

The following methods are used:—

(i) *Pressure scraping*, using the normal water pressure available in the main for propelling and controlling the machine, which preferably should be specially designed for each particular main. (See Figs. 4A and 4B.)

(ii) *Drag scraping*, using specially-designed scraping machines and either manually- or power-operated winches to draw the scraper through the main by means of flexible wire ropes. (See Figs. 5A and 5B.)

(iii) A combination of pressure and drag scraping (i) and (ii).

(iv) *Power-driven rotary scrapers.*

Rotary thrust scraping is used for small mains only (particularly where encrustation is very bad, with consequent in-ability to thread pilot rods or cable through), employing specially-designed power-driven rotary cutters operated by solid steel rods with flexible joints, or special type flexible rods.

Compressed air-driven rotary scraping machines are also used for large mains.

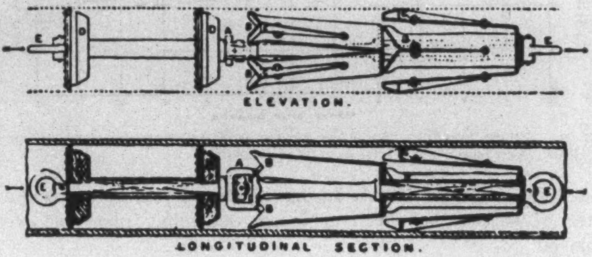


FIG. 4A.—TYPICAL PRESSURE SCRAPING MACHINE USED IN GREAT BRITAIN FOR SMALL MAINS.

(*d*) *Chemical Methods of Cleaning Mains*

Chemical methods have been employed for water mains in special circumstances, and have also been used in Manchester for the cleaning of 10 miles of hydraulic power mains laid in highways.

6. *Methods of Re-lining Water Mains* in situ *after Scraping*

(*a*) *"Eric" Process—Scraping and Bitumen Re-lining by Electrolytic Deposition*

The encrustation is removed by drag scrapers or rotary thrust scrapers, and the main is then re-coated with bitumen by electrodeposition from an aqueous solution of bitumen.

Pipe "cuts" need be only about 2 to 3 ft. long at each end of the section of main being scraped, with a 1-in. plug hole midway for use in rodding. Excavations are correspondingly small, about 7 ft. by 3 ft. for the "cuts", and about 2 ft. square for the plug hole.

The normal procedure is to drag by hand-winch successive trains of scrapers accompanied by a "wash water" flow through the main.

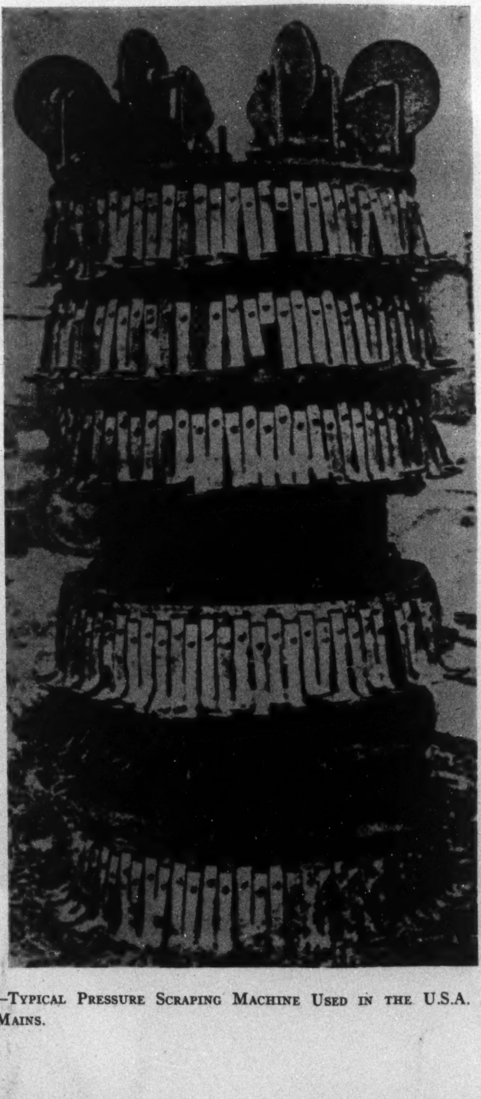


FIG. 4B.—TYPICAL PRESSURE SCRAPING MACHINE USED IN THE U.S.A. AND CANADA FOR LARGE MAINS.

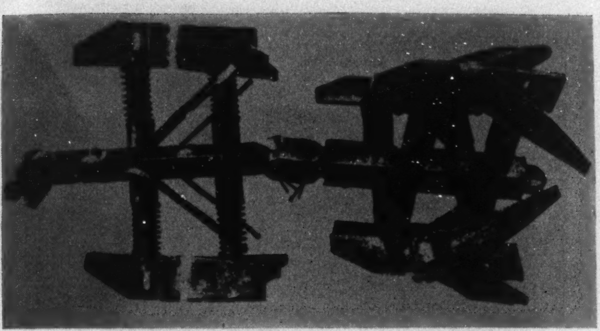


Fig. 5A.—A Typical Drag-Scraping Machine Used in Great Britain for Small Mains.

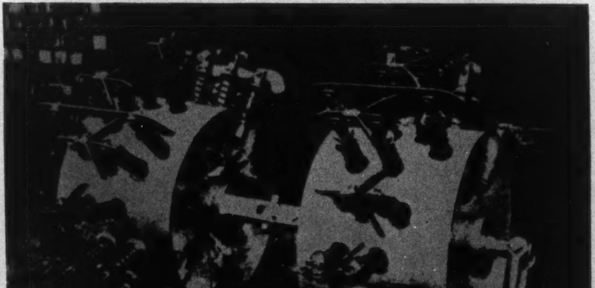


Fig. 5B.—Manchester Drag-Scraping Machine for Large Mains.

The last pull is performed using a stiff wire brush at the end of the train, together with a small flow of water to remove the last traces of debris in the main.

The time required for scraping each length should not exceed six to seven hours, after which the supply can be resumed temporarily until the next section is scraped the following day. It is usual to scrape a 200-yd. length in one day and to re-coat that section the following day while the next length ahead is being scraped. "Cuts" to be broken out again are made good by special temporary joints. They are usually "pieced up" permanently by run lead joints and double collars in the normal manner.

The bitumen coating is applied by pumping an aqueous solution of processed emulsified bitumen into the length under treatment until it is completely filled; an insulated copper electrode connected to the negative pole of the generator is then drawn through in stages. The main itself forms the other electrode, being connected to the positive pole.

Electricity is supplied by portable generators—usually direct current, at 75 to 80 volts.

As bitumen is an insulator, the electric current ceases when all exposed iron under the influence of the electrode is thoroughly coated and positive control is assured by observation of the generator ammeter.

Patches of sound old coating adhering to the mains insulate them at such points, which are not therefore coated over, but all exposed iron, even if rusty, is coated by the process.

The solution, being aqueous, is perfectly miscible in water, and pools of water standing in the invert merely dilute it slightly.

After the complete passage of the electrode through the length under treatment, the solution is pumped back into the storage tanks, any slight surplus being flushed off. The main can be put back into service immediately.

House services are unaffected provided the stop taps or draw taps are kept shut and are efficient, otherwise dirt and coating fluid will be drawn into the house service pipes during operations, with unfortunate results to the consumers.

The cost of this method of re-lining *in situ* is about one-sixth to one-quarter that of a new main, and is a very useful short-term expedient, especially for small mains with many service connections.

About 1,000 yd. can be re-lined per week.

In Manchester, about 20 miles of small-diameter mains were relined by this method in the years 1928-33; in America the process has been applied to mains up to 24 in. in diameter.

(*b*) *"Stalwart" Process—Scraping and Bitumen Re-lining by Pneumatic Spraying and Mechanical Brushing*

(i) *General procedure.*—This process was given a thorough test in Manchester between the years 1937 and 1941. Initially many difficulties were encountered, and the equipment needed much modification before complete success was obtained. However, in 1938, considerable lengths of small mains (3 in., 4 in., 6 in. and 9 in. in diameter) were successfully scraped and afterwards re-lined with bitumen, which was blown by compressed air in the form of a radial spray from a flexible container attached to a rubber pipe (see Figs. 7A and 7B). The load was drawn by flexible wire rope through the previously scraped and air-dried main by power-operated winches. After processing, the lining was dried for two hours by blowing air through the main, which was then recharged and put back into service. Sample lengths cut out at random after processing showed a smooth, even coat of bitumen.

Following the successful re-lining of the smaller mains it was decided to apply this process in the re-lining of two parallel 30-in. mains from Godley to Audenshaw (Manchester), each nearly five miles in length.

Initial progress on No. 2 main was slow, due to an attempt to use a new form of scraper without previous trial, as it was originally intended to scrape this main in two sections by means of a water-pressure operated machine. (See Fig. 8.)

This machine was built up from a 2 ft. 6 in. length of open-ended steel tube, to which were welded a number of offset pillars about 1 in. in diameter. These pillars carried the "arrow head" scraper blades, similar to those which had previously been used on the smaller scrapers. The scraper blades were all spring-loaded and arranged so as to cover the whole inside surface of the main. A shorter length of steel tube with radial scraper blades and capable of easy rotation formed the front end of the machine; the centre portion was not intended to revolve, and the tail of the machine carried a hollow wood and rubber cone lined internally and externally with lightweight steel sheeting. The water pressure against this rear cone provided the driving power, and a baffle at the forward end of the machine, with a 4-in. diameter centrally-placed orifice, caused a water jet to act upon impeller blades fixed to the spindle carrying the rotary section, and so

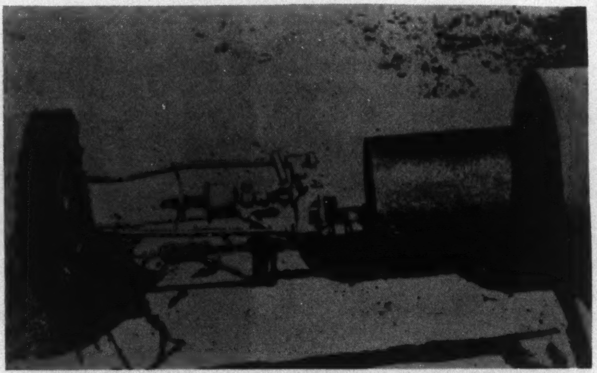


FIG. 7A.—PNEUMATIC RADIAL SPRAY, BRUSH AND CONTAINER FOR BITUMEN.

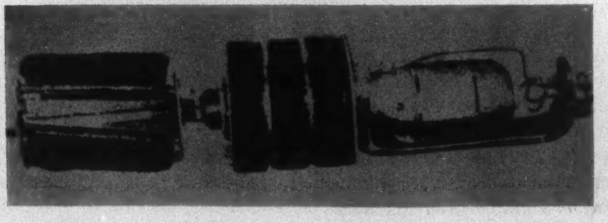


FIG. 7B.—ELECTRICALLY-DRIVEN ROTARY BRUSH FOR USE ON SMALL-DIAMETER MAINS.

cause it to rotate. No previous trials had been made with this machine and failure resulted at the outset, due to a number of causes:—

(i) Insufficient head of water available.
(ii) Too great a spring tension of scraper blades.
(iii) The excessive weight of the machine.
(iv) The large amount and weight of very hard corrosion adhering to the main.

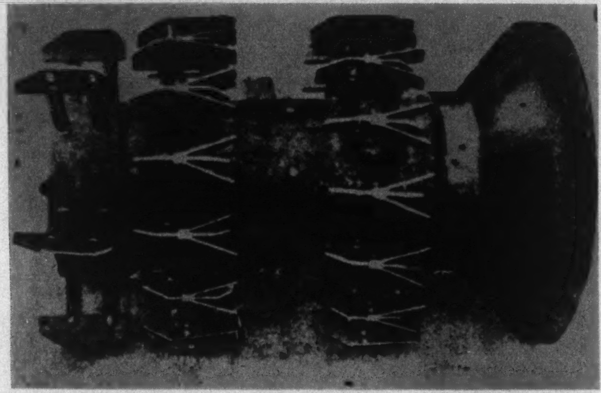


FIG. 8.—ORIGINAL PRESSURE-OPERATED SCRAPING MACHINE FOR 30-IN. MAIN.

The machine was very quickly converted to a drag-scraper, by the removal of the rotary nose and the rear pressure cone, and the attachment of suitable drag shackles.

Fordson tractors (which should preferably have 2- or 3-speed gear) with rear-mounted winches provided the power for operating the flexible drag-ropes.

"Cuts" were made at 200-yd. intervals and in practice it was found that, to scrape such a length to a reasonably clean condition, it was necessary to traverse the scraper in both directions several times; but provided no special obstructions were encountered this was done quite speedily. There was often trouble in passing a pilot cable through the main and, bamboo rods or steel rods, etc., all failing, a workman had to travel through carrying a light wire to which was attached a small hand-winch situated alongside the tractor, the heavier drag-cable being attached once contact was established at the opposite end. There was also difficulty at points where the pipe dipped under a sewer or stream, as the main was often full of water, and in such circumstances contact with the far side was made with flexible rods.

After scraping, "oversize" rubber plungers and brushes were drawn through and these implements frequently brought out a much greater quantity of corrosion and deposit than the scraper, which, although very effective in breaking up the hard encrustation, left most of it lying on the bottom of the main. At a later date, in order to reduce the load on the scraper, the sequence of operations was reversed, the plungers, without brush attachment, being pulled through before the scraper. This operation removed large quantities of soft wet corrosion and so avoided any clogging of the scraper.

It is estimated that the weight of corrosion removed in many 200-yd. sections varied between 8 and 10 tons; the total quantity removed from the two mains was about 400 tons.

Following the completion of scraping and cleaning, the main was dried out in about 30 minutes by blowing through a current of cool dry air by means of a petrol-driven "Sturtevant" blower connected to the main by a large-diameter flexible pipe. Heating the air produced condensation on the cold surface of the main and was abandoned.

The re-lining process presented problems different from those encountered on the smaller mains, one of the chief difficulties being the much larger quantity of bitumen paint required. A cylindrical container holding about 30 to 40 gal. of paint was mounted on runners in the form of two flat pieces of steel welded on edge to the underside of the barrel of the container. Compressed air was used for spraying the bitumen paint, and a small "Lister" petrol engine operated an air compressor which was coupled to a ½ in. diameter rubber air pipe wound on to a large hose reel, mounted alongside the tractor used for drawing the heavy paint container through the main. The drag cable and ½-in. rubber compressed air pipe were clipped together.

A 30-in. oversize brush was located behind the paint container, and between the brush and container was fixed the paint spray-head, the air inlet to which passed through the container. Adjustment of the simple spray apparatus was a delicate operation and required skill and judgment on the part of the operator, as adjustment had to be carried out before the spray-head entered the main. A pilot cable was fixed to the tail of the brush so that the power drag cable could be pulled back after the first coat of bitumen had been applied. (See Fig. 12.)

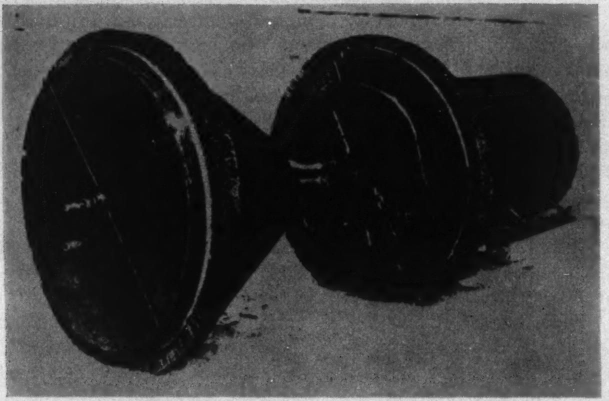


FIG. 12.—BITUMEN CONTAINER, PNEUMATIC SPRAY AND BRUSHES FOR 30-IN. MAIN.

A second coat was sprayed and brushed on after the first coat had been dried. Inevitably the first coat was damaged to a small extent by the passage of the container a second time, but a careful inspection by electric torch after drying showed that the second coat had a very reasonable surface and appearance. Occasionally, small patches were found which had not been thoroughly cleaned, and the coating had been deposited over extremely hard corrosion. It was intended to "piece up" with Johnson couplings, but, owing to deliveries being long delayed due to war circumstances, collars and run-lead joints were used.

(ii) *Discharge capacity tests before and after "Stalwart" proc-*

ess.—A flow test was carried out after processing, the maximum discharge into Audenshaw Reservoir being measured by weir. Table I gives the respective flows. Both No. 1 and No. 2 mains had been "pressure-scraped" 16 years previously, without bitumen re-lining.

TABLE I
DISCHARGE CAPACITY TESTS ON GODLEY NOS. 1 AND 2 30-IN. MAINS

Date Laid	Max. Discharge when New: *m.g.d.*	Discharge before Scraping, 1925: *m.g.d.*	Discharge after Scraping under Pressure, 1925: *m.g.d.*	Discharge before Drag-scraping, 1940: *m.g.d.*	Discharge after Drag-scraping and Re-lining by Stalwart Process, 1941: *m.g.d.*	Discharge, 1947: *m.g.d.*	Discharge, 1949: *m.g.d.*
GODLEY NO. 1 30-IN. MAIN:							
1865	22.7	8.7	13.25	10.0	18.5	16.0	15.5
GODLEY NO. 2 30-IN. MAIN:							
1899	24.0	11.7	13.85	12.5	20.0	18.35	14.0

(iii) *Cost of re-lining 30-in. mains by the "Stalwart" process.*—Work was begun on 29th June, 1940, on No. 2 main, and the whole length of 7,313 yd. was completed by 31st October, 1940. The total cost was £5,571, or £0.762 per yd. The processing of No. 1 main was commenced on 19th November, 1940, but was suspended on 24th December, 1940, as it was required for supply purposes following enemy air activity and damage in the Manchester area. Work was recommenced on 2nd July, 1941, and completed on 18th November, 1941, a length of 7,850 yd. having been processed. The cost of carrying out the work on this main was £6,145 or £0.783 per yd.

Thus, the total cost of re-lining both mains in 1940–41 was £11,716, which is one-thirteenth of the 1939 estimated cost (£152,000) of new replacement mains.

(*c*) *"Tate" Process—Scraping, Proving and Re-lining with a Medium Thickness Lining of Cement Mortar by Mechanical Means*

This process was first developed in Australia and was extensively used in Sydney about 1930–32 before being introduced into Great Britain about 1933–34 under British patents.

(i) *"Tate" process—British practice.*—Early in 1934 the Manchester Corporation Waterworks entered into a contract with the Tate Pipe Lining Processes Company Limited, of London, for the cleaning and re-lining with concrete *in situ* of 10 miles of mains of 3-in., 4-in. and 5-in. diameter, and the whole of this length was completed satisfactorily by the end of September of that year. The process was applied each succeeding year up to 1942, by which time a total of 64 miles of mains of sizes varying from 3 in. to 10 in. in diameter had been re-lined successfully. Wartime difficulties stopped the work in 1942, but early last year (1949) further work of the reconditioning of 9-in. and 4-in. diameter mains *in situ* by this process was undertaken.

Briefly, the process as applied to a heavily-encrusted 4-in. service main with many house connections is as follows.

Excavations are made about every 100 yd. along the main, as shown at points A, B and C on the diagram (Fig. 13). All house connection ferrules and other connections are then removed, smaller excavations (f, f, f, etc.) being made for this purpose. These connections are replaced by temporary screwed plugs, so fixed as not to project beyond the inside surface of the main.

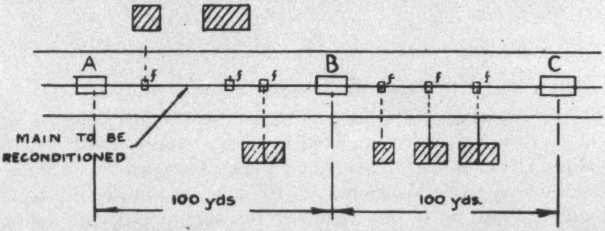


Fig. 13.—Diagram Illustrating Sequence of Operations in Applying the "Tate" Process.

A piece of main about 8 ft. long is then removed at point A, and the apparatus for scraping is inserted.

The rotary thrust cleaning machine consists of a petrol-driven engine travelling on rails and hand-wound along a worm screw running through the centre of the excavation. The engine rotates a spring-loaded spear-shaped thrust scraper, and hand winding along the screw propels the scraper into the main by means of the successive attachment of solid steel rods with flexible joints, each 6 ft. long. Over 200 yd. can be scraped with this means at one operation, the main being cleaned to the bare metal. In order to save time on successive operations, in addition to the cut at A the main is usually cut at C while the cleaning machine is being erected at A, and the length of main at C is then immediately replaced with "Gibault" or other suitable temporary joints. During the whole time the scraper is being propelled into the main, a flow of water is maintained in the reverse direction to wash out the broken-up corrosion into the excavation at A, from which it is pumped continuously. Following the completion of the scraping of the length A to C, the main is heavily flushed to complete the removal of loose deposit, and the cleaning machine and all its attendant apparatus is then removed.

The pipe at C is again removed, but if desired the length beyond C can then be put back into service by fixing a cap on the end of the unscraped section. A further piece of main 3 ft. long is then removed at point B. Hand-operated winches are brought to points A and B, and the preparation for concrete lining the length A–B is begun.

Bamboo rods are passed through the main and a flexible cable is pulled through from winch at B to point A. To this cable are attached rubber "plungers", each consisting of two oversize disks of rubber about ½ in. thick, reinforced with a large-diameter steel plate and connected together by means of a short steel rod. Between two such plungers is connected a similar piece of equipment known as a "prover", consisting of a steel piston at one end and a rubber disk at the other, the steel portion being rather smaller in diameter than the main. As its name suggests, its purpose is to "prove" the size of the main, thus ensuring that no obstacles remain which might obstruct the later passage of the lining machine. (See Fig. 15.)

The plungers and prover are drawn through from A to B by winch at B, a trailing cable from winch at A being attached. Any obstructions are thus quickly encountered and after location, if necessary by inserting bamboo rods in the main to find the position of the prover, are then removed by cutting out that part of the main. The plungers remove the remaining loose deposit and any pockets of water and leave the main ready for lining.

The cable from winch B is now drawn to point A and the cable from winch A is detached, and a "loading tee", very similar to a hydrant branch, is then affixed to the end of the main at A. A flange carrying a 2-in. bore pipe rising vertically from the loading tee is then fixed and the open end at the back of the tee is temporarily covered with a two-bolt flange. A large loading funnel projecting above ground is then fixed to the top of the 2-in. vertical pipe. (See Fig. 16.)

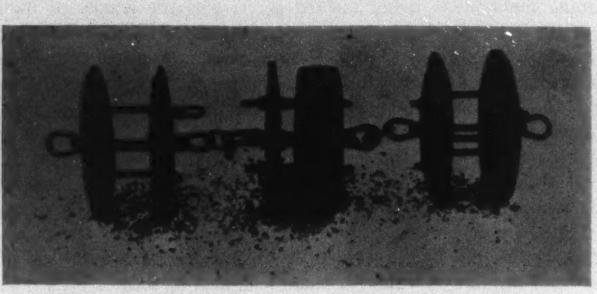


FIG. 15.—PLUNGERS AND PROVER.

As soon as it is known that the prover has successfully passed through the main, mixing of the concrete adjacent to the loading point is begun.

Washed sand and cement in the proportion of 2 to 1 are mixed either by hand on large galvanized-lined trays or by a lorry-mounted rotary drum machine mixer of large capacity, according to the quantity required. Careful mixing for 45 minutes after wetting is carried out and a "slump" of 8½ in. to 9 in. is effected before loading commences. In the case of small mains, loading is by buckets direct into the funnel for the first few cubic feet, being later assisted by hand-plunging with a steel T-shaped tube carrying a rubber and metal disk at the base; but for large mains loading is by gravitation. When loading is complete, the funnel and vertical pipe are detached and replaced with a blank flange. The end flange of the loading tee (to which the cable lying in the main is temporarily anchored) is also removed and the lining machine attached to the end of the cable.

The lining machine consists of a brass or aluminum boss with a tapered hollow steel end or skirt, having a number of rows of countersunk holes. A shackle eye at the front end provides the towing attachment, and the whole machine is maintained centrally in the main by means of strong spring-steel guides, bearing on the unlined portion.

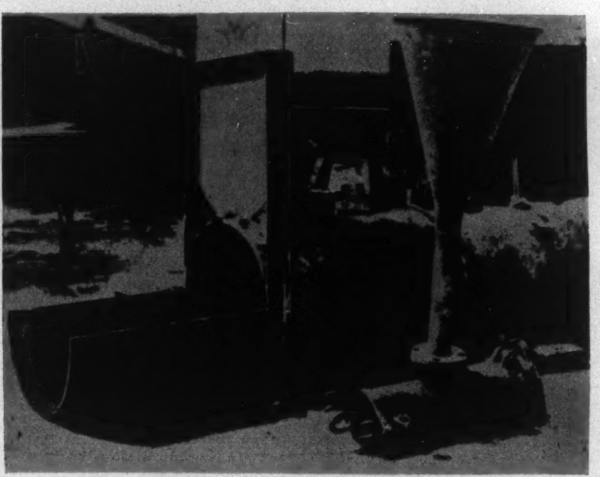


FIG. 16.—20-IN. AND 6-IN. "TATE" LOADING TEES.

The diameter of the skirt at the trailing end is equal to that of the main when lined with a 3/16 in. thick lining. Rotation of the winch at B draws the machine into and through the main to point B at a speed of about 12 to 15 ft./min. The cement mortar in the main is pushed ahead by the machine and the pressure thus created (augmented if necessary by a "baffle" a few feet in front of the machine) forces the mortar over the skirt, the taper creating an increasing pressure (about 130 lb./sq. in.) thus causing the mortar to adhere to the walls of the pipe. Excess moisture is forced through the "dehydrating" holes and flows out through the open end of the skirt and falls to the invert of the main, where it forms a distinctive "flat". As the machine approaches point B, artificial pressure is applied by hand when the mortar begins to emerge from the main by holding a funnel-shaped bag over the out-coming cable; in the case of large mains the pressure is controlled by fixing to the end of the main where the machine is to emerge a special horizontally-hinged tee pipe of such a length as to accommodate both the baffle and the machine on completion of the lining.

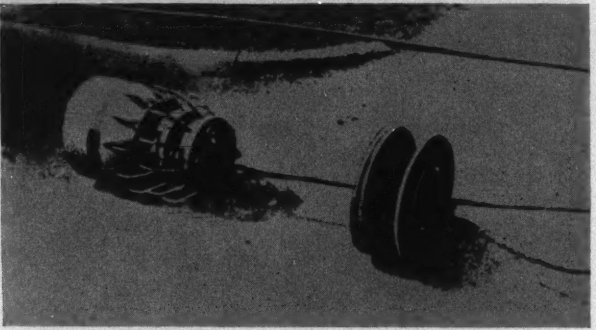


FIG. 19A.—"TATE" LINING MACHINE AND "BAFFLE" FOR 15-IN. MAIN.

When the lining machine finally emerges at point B the re-lining of the section A–B is complete. (See Fig. 19A.)

If scraping has been accomplished in the early part of the day and the re-lining by the late afternoon, the section so treated is then left until the following morning when the main is connected up at point A. In the case of service mains, any house connections are replaced after the removal of the temporary plugs and the careful cutting away of the lining immediately below the bottom of the plugs. Following cleansing by flushing, the main is then put into service by fixing a cap at B, leaving the next section B–C ready for treatment. The usual procedure is, however, to clean from A to C in one operation and line this length, A to B and B to C, the same day, thus permitting the cleaning of the length ahead the following day during the time the completed section is being put back into commision. To avoid undue hardship to consumers, a by-pass of 1-in. copper tube is frequently laid above ground and the house connections coupled to it temporarily, thus maintaining a supply during the treatment of the main. For larger mains, 4-in. or 6-in. victaulic-jointed by-pass mains are often used to maintain the supply.

Many complaints of excessive hardness of water are usually received immediately following the processing, but after flushing each day for about a week the temporary hardness disappears. The supply when restored invariably shows a considerable increase both of pressure and flow. (See Table II.)

TABLE II
MANCHESTER WATERWORKS
WATER MAINS RE-LINED *in situ* BY THE "TATE" PROCESS
Comparison of flows—1934 and 1949

		Standing Pressure		1934		1949	
Manchester District	Diameter of Main: *in.*	1934: *lb. sq. in.*	1949: *lb. sq. in.*	Flow before Processing: *g.p.m.*	Flow after Re-lining: *g.p.m.*	Present Flow: *g.p.m.*	Percentage loss of volume since 1934
Woodville Terrace, New Moston	3	50	45	26	55	40	25
Beverley Street, Blackley	3	50	50	38	105	100	5
Grosvenor Street, Cheetham	3	50	60	50	170	140	17
Darlington Street, Cheetham	3	50	60	50	120	100	17
Heath Street, Cheetham	4	50	80	100	200	200	nil
Greenhill Road, Cheetham	5	40	35	160	235	200	15
Hall Road, Crumpsall	3	40	42	80	140	140	nil
Portland Place, Rusholme	3	48	40	Not known	110	100	9

It should be mentioned that the sections of pipe cut out and afterwards used for "piecing up" the main after lining are lined above ground, whilst a flexible machine is used for the lining of bends.

The greatest benefit is derived when the "block" system of reconditioning is adopted instead of treating isolated lengths of main. This system involves the reconditioning of all mains in a compact reticulation area. On the other hand it is frequently found that, when the principal feeding main of 5-in. or 6-in. diameter has been treated, the immediate general improvement effected in pressure and volume is sufficient to justify the non-treatment of the smaller 3-in. and 4-in. service mains.

Although the contract price per yd. is naturally higher for 6-in., 9-in., etc., diameter main than for the smaller service mains, the dislocation to supplies generally is much less when the larger sizes are being processed, and the work is speedier. The highway reinstatement costs are much less for mains over 6 in. in diameter owing to the smaller number, or the complete absence, of house connections. There is also much less likelihood of failing to locate any lead service pipes, which if not disconnected from the main are filled with cement mortar.

Many obstructions are encountered both in the scraping and proving of mains. "Fishes" of lead, protruding plugs, ferrules left in and not located, bad joints in collars or sockets, are but a few of the difficulties met with.

Rotary Thrust Scraping versus Drag Scraping for Small Mains

Although the rotary thrust scraping machine is thoroughly efficient in operation, the cleaning can also be accomplished with drag-scrapers and wire brushes with equal efficiency. The Tate Company prefers to use drag-scrapers wherever possible, drawn either by hand or power winch, but for very heavily-encrusted small mains rotary thrust scraping is essential. The apparatus required for drag scraping is much simpler and the scrapers can be drawn through in each direction until all the corrosion is removed. The blades of the scrapers and those carrying the wire brush pads are all spring-loaded, and the tension can thus be adjusted to accommodate any main that is undersized or oversized, a difficulty which occurs frequently in scraping old mains.

Concrete Mixture for Re-lining—Experience and Difficulties

The concrete for re-lining offered many problems in the early operations. At first, normal slow-setting Portland cement and river sand were successfully used, but, in order to effect some saving of time in recommissioning the main after treatment, experiments were carried out with "Ferrocrete" (rapid hardening) cement. Although some time was saved between completing the re-lining and charging up the main for service, the resultant mix of "Ferrocrete" and sand was very "fat" and gave an increased slump on the bottom of the main behind the lining machine. "Ciment Fondu" was then tried with sand and an admixture of slate dust to form a lubricant. The use of "Fondu" appealed to the authorities at Manchester, as water could be turned into the main within a few hours of lining and the supply to consumers resumed immediately. The "time limits" for working with "Ciment Fondu" were, however, much finer, and it was difficult to achieve consistently satisfactory arrangements for securing the correct slump and ease of loading quantities into the main. It was found very difficult to treat a long length in one operation owing to the rapid set of the mixture in the main while loading and lining were in progress.

Several samples of small-diameter main re-lined with "Ciment Fondu" mix have recently been cut out and inspected. In many cases there appears to be a general breaking up of the lining, beginning with a flaking of the surface. Pending further evidence it is believed that, with lapse of time, the slate dust which was added to form a lubricant has now begun to separate and is causing a general disintegration of the lining.

Occasionally, probably due to oversize mains with a consequently reduced pressure from the lining machine, the wet mix would blow past the end of the machine, thus causing a wave-like obstruction; for a short period, a ball was passed through the main in order to locate any such "waves" after lining, but this was abandoned on the reversion later to the use of normal Portland cement.

Some small trouble has been experienced with a few mains several years after re-lining, but, on investigating the very full records kept, reasonable explanations of the causes of the trouble have usually been formulated. In certain cases, flaking of the surface of the lining subsequently occurred for no apparent reason, and large quantities of flaked lining were washed out during routine cleansing. It was found that the cement used for these linings had been either old or otherwise of doubtful quality, and in other cases a different type of sand had been tried. However, when fresh normal Portland cement and washed river sand were used for the re-lining, very little trouble was experienced; of all the many samples cut out in later years, very few have shown any defects and, apart from a discoloration, the lining appears to have suffered no deterioration.

Recent Improvements and Developments

During recent years improvements in some of the details of the equipment have been made, more especially in the adoption of mechanical mixing for the concrete and in applying the process to the re-lining of larger mains up to 24 in. in diameter, although the lining machine remains basically the same.

Recently, in order to maintain full supply during the reconditioning of larger mains of 9 in., 12 in. and 15 in. diameter, a by-pass of 400 to 600 yd. of 6-in. steel main with victaulic joints is laid above ground in a similar manner to that adopted by the National Fire Service to supplement the supply during the war. This procedure permits the work of reconditioning the larger diameter mains to be carried out with only slight intermittent interruptions of supply, and any difficulties or delays which arise during the cleaning and re-lining do not affect consumers.

(ii) *"Tate" process—Australian "pull-through" practice.*—The Sydney Metropolitan Water Board originated and developed the "pull-through" process of cement lining *in situ* with its own staff and resources, and since 1931 has carried out by direct labour a very extensive re-lining programme using this method. Many other water authorities have also had similar work carried out under contract by Cement Linings Proprietary Ltd., using the same process.

Sizes and Lengths of Mains Re-lined with Cement

The lengths of mains lined *in situ* since 1931 by the Sydney Board are as follows:—

4-in. Cast iron	1,060 miles
6-in. Cast iron	192 "
8-in. Cast iron	52 "
10-in. Cast iron	11 "

Further re-lining has been restricted since the war, but preliminary tests are in hand for the lining of a 15-in. main.

Unfortunately, accurate figures of the lengths of mains lined by contract outside the Sydney Board area are not available, but about 75 authorities have utilized the process.

Re-lining Process

Basically the process is the same as the "Tate" process operated in Great Britain and elsewhere, as previously described, but, following considerable experimental work in 1930–31, variation in the design of the tapered steel skirt of the lining machine has generally been adopted. The nominal thickness of cement lining for 4-in. mains is 3/16 in., and the speed of travel of the lining machine is usually about 18 ft./min. Daily target is 600 ft., usually lined in two lengths.

The skirt of the lining machine in general use in Australia now has a number of helical slots cut in the rear; these slots replace the holes in the skirt as used in Great Britain, etc. The use of slots instead of holes has allowed a much drier and coarser mix of cement mortar to be employed and, in the opinion of the Sydney Board, has resulted in a more even and reliable lining.

The mortar mix is 2 cu. ft. of dry sand to 96 lb. of cement. For mortars to be used with the perforated skirt, water contents are used to give a slump of about 9 in., but for machines with the slotted skirt the slump required is from 2½ to 5 in. according to weather and other conditions. Consistency governs performance.

(In this connexion it may be noted that a slotted skirt was used in Great Britain some years ago on experimental linings with the "Tate" machine, but was abandoned in favour of the perforated-hole type of skirt.)

Scraping and Cleaning

Cleaning of the mains prior to cement lining is carried out by both under-pressure machines and winch-drawn drag-scrapers and brushes. In addition, rubber plungers and drying mops are also used to remove deposit and greasy "black rust". It has been found that better lining adhesion is obtained following the use of this latter operation. Proving of the main is identical with methods employed elsewhere.

Suction Loading of Mortar into the Main

The loading of the cement mortar into the main is carried out by suction, this method replacing manual loading and plunging. Mortar of suitable consistency for lining either by the perforated or slotted skirt type of machine can be drawn into the main by means of a vacuum pump, but a piston interposed in the dragging cable and creating suction is now generally used. The piston consists of two rubber disks supported on a shank; the disks are so spaced that the clearance spaces in joints and tees are spanned by the pistons and very little suction is thus lost by infiltration of air. Prior to the evolution of this system, a process of pre-distribution of mortar was used when operating with the slotted skirt. Slotted drag cones supported by short strip springs were dropped over the dragging cable and carried through the loading hopper and the main at fixed spacings determined by buttons on the cable. By this method a relatively dry, coarse mix, giving a firm lining, was introduced into the main.

When cement lining *in situ* was commenced, the oldest mains were lined first, excluding those mains known to be much wasted by corrosion. As the number of gangs operating the lining process increased, it was found more economical to line all mains in any given area, irrespective of age, the gangs working radially from a temporary depot.

(iii) *"Tate" process applied to the re-lining of steel mains in Uganda, East Africa.*—The process was applied in 1936–37 to about 48 miles of steel mains in Uganda, East Africa.

Although these steel mains had only been laid in 1928 and were thus comparatively new, considerable trouble was being experienced from discoloured water due to rusting, and extensive and severe interior pitting of the main caused by the action of the untreated Lake Victoria water. As the re-laying of the mains was not possible, reconditioning of the entire system was adopted. Up to 1936 the "Tate" process had been carried out in Australia and England on old encrusted cast iron mains to improve supplies, and the work in Uganda was the first instance of its application entirely as a protective measure.

The work occupied about 12 months and many difficulties of a different nature from those encountered on similar work in England had to be overcome. The process generally was performed in a similar manner to British contracts, but on a larger scale, four gangs each of about 50 natives supervised by Europeans, being employed.

Whereas in England temperature, apart from frost, had little or no effect on the process, in Uganda its effect was extensive. Between the operations of proving and of re-lining the mains, an additional operation was necessary. Owing to the great heat, the main had to be cooled as far as possible after proving by filling with water and emptying and plunging again immediately before loading the main with mortar for lining. Sand was another difficulty, for, although large tracts of sand existed, few of the areas offered sand of a suitable nature. The first deliveries came by barge from an island 60 miles out in Lake Victoria, and the lining operations attempted when using this sand produced very erratic results. The coarseness of the sand caused so much friction during the passage of the lining machine that frequently the machine became jammed and the whole of the cement mortar had to be washed out under pressure and a further attempt made. After many trials and errors, including the use of a sand pulverizer, a suitable sand, requiring only washing and drying, was ultimately located at a nearby swamp. This sand was afterwards used throughout, and very little trouble was experienced with the actual lining operation.

The cleaning process prior to lining was carried out by drag-scrapers and hand-operated winches, and this work was fairly free from difficulties. No great accumulation of corrosion was found in the varying sizes of mains (3 in. to 10 in. diameter), but the bitumen paint on the interior, particularly in the larger diameters, caused considerable trouble. At the time the mains were laid, it is assumed that the pipes were left lying alongside the trench and that the excessive heat caused the paint inside to leave the top and walls of the pipe and collect on the invert. In many cases it was impossible to remove this accumulation and the concrete re-lining was carried out over the paint.

Although the mains had been laid as recently as 1928, their location and that of the services was often extremely difficult due to the abnormally heavy growth of vegetation. An "electrical main-finder" was used extensively with great success, and although in England lead services were occasionally overlooked and subsequently filled with mortar by the passage of the lining machine, such occurrences in Uganda were rare.

In comparing the reconditioning methods in Manchester with those used in Jinja and Kampala, Uganda, it is worth noting that, in the African work, the entire system of trunk and distribution mains was re-lined, whereas in Manchester, although the side branch mains were fully processed, the short length between the valve and the branch out of the feeder main was only scraped, the feeder main frequently being left untreated. It is to be anticipated that a more rapid recurrence of encrustation will therefore take place in the short length of main referred to, although the removal of encrustation from this section produced at the time a considerable improvement of flow in the branch main.

In order to maintain continuity of concrete lining in the future, the Public Works Department of Uganda arranged to line all pipe stocks held in the depot, and accordingly these pipes, bends, branches, etc., were laid in lengths along the Lake shore, roughly yarn-jointed and anchored with steel bars, wire brushed and then lined with concrete. Twenty-four hours after lining, they were rolled into the Lake to effect the curing of the concrete before re-stocking in the depot.

During the lining of many of the supply mains, a number of necessary services were maintained by the laying of 2-in. and 3-in. galvanized iron by-pass mains with screw joints, with flanged joints at intervals to facilitate removal and re-laying.

A considerable degree of skill was achieved by many of the natives in the use of oxy-acetylene for pipe cutting and joint welding, together with the subsequent operations of piecing up of the completed sections. Although minute-by-minute supervision of the native labour was necessary, due in no small measure to their enthusiasm, the work was carried out and completed in an entirely successful manner.

(*d*) *"Centriline" Process—The Scraping and Placing of a Centrifugally-applied Cement Mortar Lining by Special Machine Operating Inside the Main*

This process originated in the United States about 1933 and was first applied commercially in September, 1935, after six years of experiment, for the reconditioning of 9,182 yd. of 48 in. diameter riveted steel main at Newark Waterworks, New Jersey, U.S.A. During the last 14 years over 150 miles of mains varying from 24 in. to 90 in. in diameter have been re-lined *in situ* by the process, which can be applied equally well to cast iron, wrought iron and steel. Successful results have been obtained with lap-welded, lock-bar and riveted steel mains, even when much distorted, pitted and perforated. Newly laid unlined mains have also been lined with cement mortar by the process before being put into service.

Scraping is usually carried out by hydraulic pressure machine for mains up to 60 in. diameter (see Fig. 4B), supplemented by hand-scraping.

The *re-lining* is performed by a machine of special design adapted to each size of main to be processed.

Entry to the main is necessary at intervals varying from 1,000 ft. to 1,500 ft., and in the absence of permanent manholes is obtained through temporary openings by cutting out a short length of main called a "dowel".

The cement mortar is composed of one part of washed and dried sand to one of normal Portland cement, and is mixed mechanically for three minutes above ground. The water-cement ratio (which is usually 0.30 to 0.35) is carefully controlled in order to secure the correct consistency and a lining of maximum density. The mortar must be relatively dry to give good adhesion to the wall of the main, and prevent "falls" of the newly placed lining; the "slump test" averages about 2 in. After mixing, the mortar is fed from the surface through a chute into a hopper mounted on a rubber-tyred bogie inside the main under treatment, and is then transported along the main to the lining machine, thus securing a continuous supply of freshly mixed mortar. The transporting bogies are powered by electric motor.

The centrifugal lining machine is illustrated by Figures 21 and 22, from which it will be seen that it consists of a chassis-mounted storage hopper into which the mortar is loaded from the transport bogies. The rear of the hopper is tapered and connects with a horizontal tube through which the mortar is forced by means of a screw-feed conveyor, carried on a longitudinal shaft, to a "spinner" or distributing head at the rear end of the machine. The machine has two electric motors, one with variable-speed transmission for traction, and the other of constant speed for driving the worm-feed conveyor, the "spinner" and the trowelling arms. The mortar is forced at a constant rate to the centre of the cylindrical lining head, which has a series of rectangular or slotted openings around the circumference. As the mortar emerges from the orifices it is thrown by centrifugal action against the inside of the main by radially-spaced high-velocity vanes which rotate outside the "ports" at a speed of 1,000 r.p.m. The high-speed driving shaft of the "spinner" is hollow, and carries in its interior a slow-speed shaft, which turns at 3 r.p.m., upon which are mounted immediately behind the "spinner" four steel spring-loaded trowels curved to the radius of the main; these are carefully adjusted to compress the lining to a smooth hard finish. The thickness of the lining is frequently 3/16 in. or ¼ in. and is regulated by the rate of travel of the machine; a rate of 3¼ ft./min. produces a lining of ¼-in. thickness, and a travel of 1¾ ft./min. a lining of ⅝-in. thickness in the case of a 48-in. main. Progress is claimed to be 500 ft. to 1,000 ft. per day.

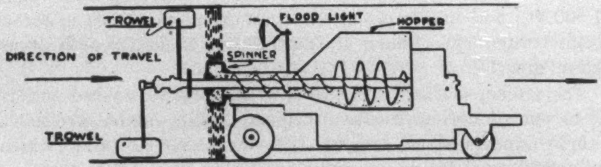


FIG. 21.—"CENTRILINE" CENTRIFUGAL LINING MACHINE—DIAGRAMMATIC.

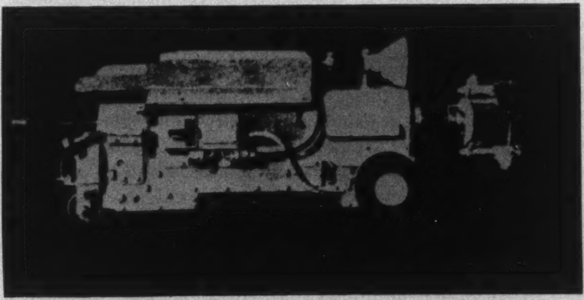


FIG. 22.—"CENTRILINE" MACHINE FOR LINING 24-IN. MAIN.

The machine is equipped with telephone and flood-lighting to facilitate the work. Electricity is generated at the ground surface, and supplied to the machine through flexible cable wound on reels. Experience shows that on gradients the direction of the lining operation should be uphill, in order to secure the best results, and to facilitate the delivery of mortar to the lining machine.

The principal feature of the process is the high velocity projection of the cement mortar on to the surface of the main.

Costs.—The costs of reconditioning mains by this process are claimed to be only one-sixth to one-tenth the cost of a new replacement main.

(*e*) *"Preload" Process—The Scraping and Placing of a Pneumatically-applied Cement Mortar Lining*

(i) *American practice.*—The "Preload" lining process also originated in the United States, and is substantially the adaptation of the "cement-gun" by special machine to the re-lining with cement mortar of mains 24 in. or more in diameter, supplemented by mechanical trowelling to produce a hard smooth surface. (See Fig. 25.)

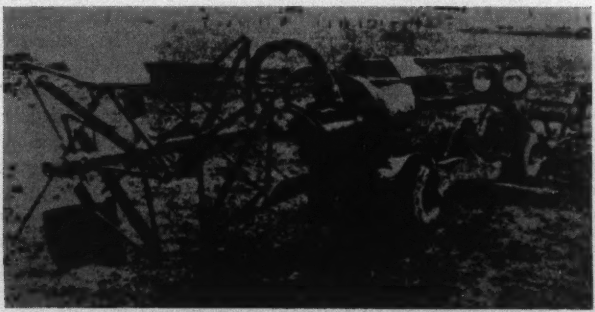


FIG. 25.—"PRELOAD" LINING MACHINE AT MANCHESTER.

The main is first cleaned by one of the usual scraping and cleaning methods.

The pneumatic pressure type machine consists of an undercarriage, an integrating operating head which is movable up and down and from side to side under the control of the operator, a central shaft to which are attached the hoses for conveying the lining materials, air and water supply, a revolving nozzle which shoots the mortar, the trowelling mechanism and inspection lights. The machine is operated by compressed air motors.

Before lining, bad joints, bad connections and leaks are repaired, and branches and other openings are covered with shields. The lining is "shot" normally to the surface of the main at a radial speed of over 300 ft./sec. by means of a nozzle which is revolving at approximately 60 r.p.m. about the central shaft. The pre-mixed dry materials from the pneumatic gun above ground are conveyed through the hose lines by compressed air to the nozzle of the lining machine, where they are hydrated. The water is admitted into the nozzle through small holes which produce very fine jets which enter the stream of moving sand and cement, and the fully hydrated lining mixture is then "shot" into place on the wall of the main. The spring-loaded trowelling mechanism follows the freshly placed lining, and maintains a constant pressure on the lining even in pipes which are considerably "out of round". The four trowels are adjusted for progressively lighter spring-loadings, and overlap so as to produce a dense smooth finish. The water-cement ratio must be kept at a minimum.

Only the operator and one helper are needed inside the main. The pneumatic gun, air compressor, cement mixer, air blower and/or extractor for ventilation, and all other auxiliary equipment are at the ground surface. The hose supply lines are gradually withdrawn as the machine moves along the main in the direction of the surface equipment. The rate of lining is up to 1,000 ft. per day, and its thickness is governed by the rate at which the machine is propelled. The latest type of machine is fitted with automatic thickness devices which require little or no adjustment during operation.

Costs are about one-sixth to one-tenth that of the full cost of a new replacement main.

(ii) *British practice at Manchester—Reconditioning of the Manchester Thirlmere Aqueduct, Lostock Booster Station to Walkden—three pipelines 36 in., 40 in. and 44 in. in diameter.*—In June, 1949, when the work of scraping the three pipelines was commenced, no process was available in England for the concrete lining *in situ* of such large pipes, but later in the year the "Preload" process became available, operated by Preload (Great Britain), Ltd. A contract was arranged for the lining of a total of approximately 18½ miles of 36 in., 40 in. and 44 in. diameter pipes. The Manchester Corporation elected to perform the necessary scraping with specially designed and proved equipment, and also, after lining, to spray a protective bituminous coating over the newly placed concrete.

After much difficulty and delay, the Company received permission to import a lining machine from America, and upon its arrival in England preliminary test linings on surface-laid 44-in. pipes were put in hand at once, and extensive equipment was assembled and workmen trained in its use. Field work on the concrete lining of the aqueduct pipes was commenced in January, 1950.

Most of the initial difficulties, some of which will be referred to later, now appear to have been overcome and progress has improved steadily. On this section the Thirlmere Aqueduct consists of three lines of pipes and, at suitable locations at each side of stop valves, the lines have been interconnected so as to enable individual lengths to be shut off for reconditioning.

Scraping

Excavations are made at approximately 220-yd. intervals and a 6-ft. section of pipe is cut out by machine; at each end of the full length of pipe to be reconditioned, a 12-ft. length is removed to permit the entry and removal of the lining machine. Two Fordson Major tractors, upon which are mounted two-speed Cooke winches, one situated at each end of the section being scraped, operate the drag-scrapers. A 9/16 in. diameter wire cable from each winch is attached to the appropriate end of the scraper, which can then be pulled backwards and forwards through the pipe.

The scraper (see Fig. 5B) consists of two separate 1 ft. 6 in. lengths of 24 in. diameter steel tube, connected by a universal joint to permit movement between the two, but not separate rotation, with a heavy draw-shackle mounted centrally at the front and rear of the complete unit. Sixteen scraper blades are mounted radially in staggered formation on each chassis, each blade being carried by two spring-loaded pillars, with provision for considerable adjustment of the spring tension. Each scraper blade consists of a main steel blade 8 in. long with wing attachments to form an arrow-head. Each chassis carries four guide blades, also mounted on spring-loaded pillars, which have a greater spring tension than that employed for the scraping blades, thus maintaining the whole machine in a central position in the pipe and thereby ensuring equally effective scraping all round. When the scraper is entered into the pipe it is placed in a hinged cone which compresses the springs and so facilitates smooth entry. The same chassis is used for 36 in., 40 in. and 44 in. diameter pipes, with varying lengths of pillar for the different diameters. Usually four or five traverses of the pipe are needed for complete break-up of the encrustation, it being unnecessary to turn the scraper round between traverses.

A snatch block, mounted on a T-bar, is fixed between the cut ends of the pipe in the shafts to ensure a central pull for the cable which passes over a guide capstan fixed at the top of the shaft before passing on to the winch. The average speed of scraping is 30 ft./min. and, although large quantities of encrustation are brought out with each traverse, the chief duty of the scraper is to break up the encrustation which is afterwards removed by a large "plunger", consisting of two oversize ¾-in. thick rubber rings reinforced with steel disks, with short stiffening bars connecting the two rings. Large ports are cut in each ring so that, if there is a large volume of deposit, a portion can escape through the ports to be removed by the next traverse; but for the final "plunging" the ports are covered by steel disks. It has been found in practice, however, that, although the volume of deposit is very heavy, the winches and cables are fully capable of removing it in one traverse with the ports closed. Two plungers are employed, a rigidly-mounted one and the other with the two rings connected by a universal joint to permit fairly sharp bends to be negotiated. The pipe is usually well cleaned by one traverse of the plunger, but several such operations are made to ensure thorough removal of all deposit.

Although 9/16 in. diameter drag cable is used, it has been found beneficial to cut off any internally-protruding lead (sometimes 1 in. thick) in the joints, before dragging commences, as this initially caused frequent cable breakage. The four tractors employed are equipped with power-operated sprags which give excellent anchorage even in bad ground. Ex-military field telephones are used for signalling between the shafts, and it is intended to extend the telephone system over the whole site to facilitate the work, which has continued in open country throughout the winter in spite of very adverse weather conditions.

Two 3-ton mobile hydraulically-operated cranes, with four-wheel drive, a jeep, and 10 pumps at the various excavations, comprise the remainder of the field equipment.

Concrete Lining—Equipment and Operation

The "Preload" process consists of placing pneumatically a cement mortar lining, followed immediately by mechanical trowelling. Much heavy mobile equipment is required, one of the principal components being a large-capacity air compressor (550 c.f.m.), from which two air lines pass to a cement-gun trailer which carries a high mounted hopper-loading concrete mixer at one end and a 250-gal. water tank at the other. The cement-gun occupies a central position on the trailer and is connected to one of the two air lines.

Cement and sand in the proportion of 1 cwt. cement, 140 lb. sand and 4 lb. asbestos fibre are loaded from adjacent material trailers and mixed dry. This dry mix is hand-raked into the top compartment of the cement-gun, from which it is passed to the bottom or feed compartment by differential air pressure obtained from the air lines through pressure-reducing valves. The base of the lower portion of the cement-gun carries an electrically-driven feed wheel, into which the dry mix passes to be introduced into the main air supply from the compressor. The air, at a pressure of 60 to 70 lb./sq. in., carries the mix along a material feed-hose made up in lengths coupled together by special brass couplings. This material hose is carried to the lining machine, 220 yd. up the pipe, on a train of two-wheeled hose carts, each 6 ft. long, lying in the pipe invert.

Water for hydration is supplied from the 250-gal. tank, being first pumped therefrom into an adjacent receiver by means of an air-driven pump. The pressure in the receiver is 140 to 150 lb./sq. in., and water is fed from it to the lining machine by means of a hose, also carried on the hose carts. Alongside the two hoses for dry mix and water, already described, there is a third hose which conveys air at about 80 lb./sq. in. to an air motor on the lining machine for travelling power.

A Diesel electric generator operates the feed wheel, and also an externally-mounted vibrator on the top compartment of the cement-gun, and a secondary generator provides current to a 32-volt lighting cable for inspection lights on the lining machine. This cable is also carried in the hose carts along with a telephone cable which provides communication between the lining machine and cement-gun operators.

The lining machine consists of a rubber-tyred chassis which carries the air motors for forward and reverse travel, and for the feed head to which the material feed hose and water supply hose are connected. The feed head rotates clockwise at about 60 r.p.m. and water enters it through holes which produce fine jets which enter the moving stream of sand and cement. The fully-hydrated cement mortar is finally "shot" from a supply nozzle on the rotating feed head on to the walls of the pipe. Four spring-loaded curved trowels are mounted on a spindle rotating anti-clockwise, so as to give an overlap, and the spring-loading is progressively lighter up to the last trowel. (See Fig. 26.)

The operator controls the lining machine from a seat fixed on the chassis, whilst two electric spot-lights illuminate the work, and the assistant operator maintains continued contact with the cement-gun trailer by telephone. The direction of travel of the machine is "backwards" towards the surface equipment and its speed is about 2 ft./min.

As the complete machine is some 8 ft. long, a 12-ft. length of pipe is removed at the first and last shafts for the initial entry and final removal, but only 6-ft. cuts are needed for the entry of the hoses and cables at the intermediate points.

In practice, the machine is entered at the first shaft whilst the gun and equipment, trailers, compressor, etc., are situated adjacent to the second shaft. The train of hose carts is placed in position in the pipe between the first and second shafts and the material, water and air hoses and cables are laid on the carts and connected to the lining machine. Between the rear end of the lining machine and the first hose cart—a distance of about 30 ft.—the cables and hoses rest on the invert of the pipe in a loop to permit some freedom of movement for the lining machine. To assist the air motor propelling the machine, a small hand-operated ratchet winch is situated in the pipe at the third shaft about 600 to 660 ft. away and the cable from this winch passes through the pipe and is fastened to the last hose cart at the second shaft. As the lining machine moves from the first towards the second shaft, the hose carts are drawn by the winch cable into the pipe length between the second and third shafts, and are thus in correct position for later use. Instead of being removed from the carts at the second shaft and laid about the ground, the hoses and cables are carried on the carts about half-way into the pipe length between the second and third shafts before being looped back to the surface equipment. This facilitates the threading through of the hoses when ready for operation on the next section of the pipe.

FIG. 26.—"PRELOAD" MACHINE AT MANCHESTER SHOWING EJECTOR NOZZLE.

On completion of the lining of each section of pipe, the machine is cleaned down as it passes through the cut ends of the pipe at the various shafts.

for inspection lights on the lining machine. This cable is also carried in the hose carts along with a telephone cable which provides communication between the lining machine and cement-gun operators.

The lining machine consists of a rubber-tyred chassis which carries the air motors for forward and reverse travel, and for the feed head to which the material feed hose and water supply hose are connected. The feed head rotates clockwise at about 60 r.p.m. and water enters it through holes which produce fine jets which enter the moving stream of sand and cement. The fully-hydrated cement mortar is finally "shot" from a supply nozzle on the rotating feed head on to the walls of the pipe. Four spring-loaded curved trowels are mounted on a spindle rotating anti-clockwise, so as to give an overlap, and the spring-loading is progressively lighter up to the last trowel. (See Fig. 26.)

The operator controls the lining machine from a seat fixed on the chassis, whilst two electric spot-lights illuminate the work, and the assistant operator maintains continued contact with the cement-gun trailer by telephone. The direction of travel of the machine is "backwards" towards the surface equipment and its speed is about 2 ft./min.

As the complete machine is some 8 ft. long, a 12-ft. length of pipe is removed at the first and last shafts for the initial entry and final removal, but only 6-ft. cuts are needed for the entry of the hoses and cables at the intermediate points.

In practice, the machine is entered at the first shaft whilst the gun and equipment, trailers, compressor, etc., are situated adjacent to the second shaft. The train of hose carts is placed in position in the pipe between the first and second shafts and the material, water and air hoses and cables are laid on the carts and connected to the lining machine. Between the rear end of the lining machine and the first hose cart—a distance of about 30 ft.—the cables and hoses rest on the invert of the pipe in a loop to permit some freedom of movement for the lining machine. To assist the air motor propelling the machine, a small hand-operated ratchet winch is situated in the pipe at the third shaft about 600 to 660 ft. away and the cable from this winch passes through the pipe and is fastened to the last hose cart at the second shaft. As the lining machine moves from the first towards the second shaft, the hose carts are drawn by the winch cable into the pipe length between the second and third shafts, and are thus in correct position for later use. Instead of being removed from the carts at the second shaft and laid about the ground, the hoses and cables are carried on the carts about half-way into the pipe length between the second and third shafts before being looped back to the surface equipment. This facilitates the threading through of the hoses when ready for operation on the next section of the pipe.

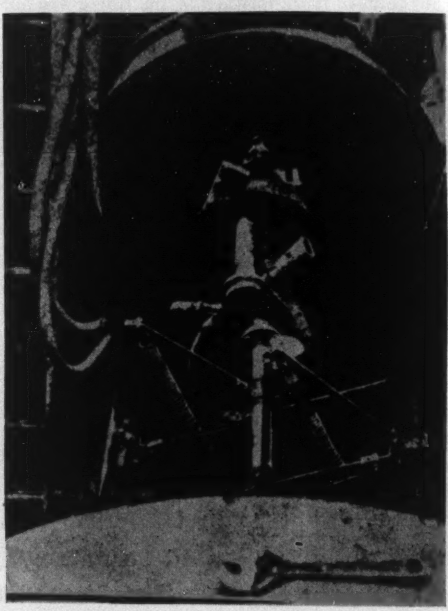


FIG. 26.—"PRELOAD" MACHINE AT MANCHESTER SHOWING EJECTOR NOZZLE.

On completion of the lining of each section of pipe, the machine is cleaned down as it passes through the cut ends of the pipe at the various shafts.

Ventilation

In order to effect adequate ventilation and to draw away any dust, etc., from the operators inside the pipe, a large motor-driven extractor fan is used at the next shaft forward of the lining machine. This fan is surface mounted and connected to the pipe by canvas envelope.

Thickness and Quality of Lining

Hand finishers enter the pipe after the initial set of the concrete, and proceed to remove any dust, etc., adhering to the lining, and, by means of ordinary plasterers' steel floats, remove any ridges or remedy other blemishes left by the mechanical trowelling. Up to the present (March, 1950) the mechanical trowels have produced a fair amount of "ridging", and at times a comparatively heavy "run-off" has had to be removed from the invert, usually at the ends of the section. The finished lining is extremely hard and smooth and of good consistency, and it is anticipated that less hand finishing will be required as the work progresses. The thickness of lining is governed by the speed of the machine and the set of the trowel arms. The average thickness employed on the Manchester Thirlmere Aqueduct contract is 3/16 in., but on some short sections of riveted steel pipes a ⅜-in. thick lining has been placed. A hand-micrometer gauge is used for checking the new diameter of the lined pipe, but it is not possible to determine the actual thickness of the lining at any point by this means. The cut pipes initially removed are hand-lined before replacement.

Progress and Difficulties

In the early stages many difficulties were encountered: electrical breakdown, telephone faults, choked feed wheel, shortage of American spares, etc., were but a few of the obstacles to be overcome. It has, however, become apparent that, as the operators and workmen become more accustomed to this new type of work, progress and the quality of the finished lining steadily improve. Although it is claimed that, in America, 1,000 ft. of large-diameter pipe have regularly been lined in one day, that rate of progress has not yet been reached in England, where so far only 600 ft. have been completed in one day.

Bitumen Painting

The bitumen painting apparatus consists of a 25-gal. pressure container fitted with a standard "Aerograph" pressure head carrying the usual air and fluid pipe controls and pressure-reducing valves. The container is carried on a ball-bearing three-wheeled tubular chassis. (See Fig. 28.) Two spray guns are fixed on an adjustable centrally-mounted arm, capable of manual rotation through 180°. The operator sits on a lightweight chassis coupled to the main container-chassis and the whole equipment is drawn backwards through the pipe by means of a hand-ratchet winch. Lighting is provided by two spot-lights powered from a 6-volt battery, and a second operator maintains telephone communication with the surface site. The hose from the compressor supplying air to the container and spray guns is coupled to a special inlet gland on a large hose reel mounted on a two-wheel trailer. This

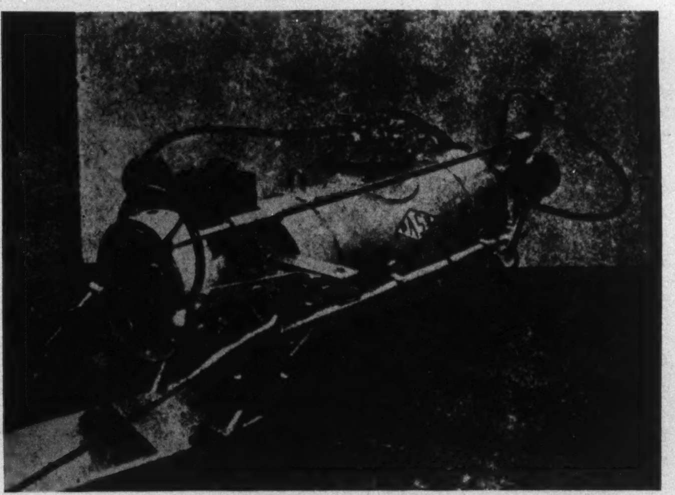


FIG. 28.—25-GALLON PRESSURE CONTAINER FITTED WITH "AEROGRAPH" PRESSURE HEAD.

reel carries 250 yd. of 1 in. diameter hose which is connected to the paint container and, as the container and operators are drawn through the pipe, the hose is wound on to the reel, the gland inlet permitting a continuous supply of compressed air during the operation. A 7,000 r.p.m. Sturtevant blower, driven by a petrol engine, provides a current of air behind the operators, blowing all fumes and fine paint spray away from them; in addition, they are provided with respirators and goggles.

Bituros bitumastic paint is used for the coating and, with correctly adjusted sprays, gives a hard high-gloss finish to the surface. Improvements and alterations are in hand with a view to avoiding the need for operators to be employed in the pipe and experiments with air motors for propulsion and spray rotation are to be carried out.

The sections of pipe removed prior to the scraping, after being cleaned, concrete-lined, spray-painted and air-dried, are then replaced and jointed with Johnson coupling joints. Finally, a mould is placed round the joint and run with bitumen, the pipeline then being charged, washed out and put into service.

New U.S.A.-type Cleaning Machine

Tests have recently been carried out with a cleaning machine of a type hitherto not employed in England, although in extensive use in America by the Preload Company.

Preliminary tests have created a good impression, and when some minor modifications have been carried out, a thoroughly efficient machine will be available.

The machine consists of a channel section chassis about 5 ft. long and 9 in. wide, carried on four small pneumatic-tyred wheels. A small air motor propels the machine in either direction through a universally-jointed propeller shaft and reduction gear to one pair of wheels. The other pair of wheels can be steered by means of a hand-lever operating a track rod and swivel pins on a small stub axle. A second air motor of 15 h.p. drives a large circular head to which are attached four curved spring steel blades, with hardened cutting tips. The operator sits on a small bogie coupled to the main chassis and all control levers are readily to hand. Three electric lights are fixed, two facing forwards and one rearwards. The machine is designed to travel backwards and the rotary cutters clean the pipe surface down to the metal and leave the encrustation and deposit loose on the invert of the pipe; under test it was found that the machine worked with equal efficiency in either direction.

When working under 60 lb./sq. in. air pressure, protruding lead through a joint caused the machine to stall; but, on increasing the pressure to 80 lb./sq. in., sufficient lead was removed by the cutters to allow the machine to proceed. The test speed was about 4 ft./min., but this is to be increased and it is anticipated that a 600-ft. length of large-diameter pipe will be cleaned in under two hours. It is the practice in America to remove the deposit left loose by the machine by hand-filled bogies, but the British Preload Company intend to employ the same type of "plungers" as those used by the Manchester Corporation for the removal of the deposit. Adjustments are provided by raising or lowering the large air motor and the cutting head to accommodate pipes of varying diameters, the machine under test being suitable for the cleaning of pipes of 36 to 44 in. diameter.

General Conclusions

Much experimental work on equipment and methods for the reconditioning of large pipes remains to be done, but the author considers that the improvements in technique which are likely to result from the work now in progress will fully justify the expenditure involved, and that the data and experience now being accumulated will be of value in future work of a similar nature.

7. *Experience and Opinion of Re-lining* in situ *in Various Countries*

(i) *Great Britain.*—The replies received in response to a questionnaire sent to 310 water undertakings indicated that, though many practical difficulties were encountered in applying the "Eric", "Stalwart" and "Tate" processes, the general opinion is that the engineering results and the financial savings amply justify the extension and further development of the practice of re-lining mains ***in situ***. About 44 undertakings have carried out reconditioning work on 680 miles of main.

(ii) *Ireland* (*Eire*).—In Dublin, Ireland, the "Stalwart" process was found to be somewhat faster and cheaper than the "Eric"—mains having a rough and pitted interior do not take a satisfactory (bitumen) lining. Many difficulties have been caused by choked ferrules and service pipes. The cost was about one-third the cost of re-laying the main—effective life increased by 15 years. The "Tate" process is approved for mains of 9 in. diameter and upwards.

(iii) *United States of America.*—It would appear that considerable re-lining *in situ* of large water mains has been undertaken during the last 14 years—using both the "Centriline" and "Preload" methods. About 35 miles of smaller mains have been re-lined by the "Tate" process; the "Eric" process has also been applied to mains up to 24 in. diameter. Results are stated to be quite satisfactory and financially attractive.

(iv) *Canada.*—The National Rapporteur at the I.W.S.A. Conference stated: "So far as I know, Montreal is the only city in Canada where large mains have been reconditioned *in situ:* seven miles of seriously-corroded steel mains 36 in. and 48 in. in diameter were re-lined with centrifugally-applied cement mortar in 1946. The lining sealed all holes in the main, provided permanent protection against leakage and internal corrosion, reduced friction losses and improved carrying capacity. The cost of replacement would have been at least 10 times greater."

(v) *France.*—No re-lining *in situ* has been carried out, but the City of Paris Waterworks propose to experiment with the "Centriline" method and are making active preparations for reconditioning a 31-in. cast iron and a 60-in. concrete main.

(vi) *Belgium.*—No undertaking has up to the present attempted the re-lining of water mains *in situ.*

(vii) *Holland.*—Forty-five water undertakings had no experience of re-lining *in situ.* The Government Institute for Water Supply reports that a modification of the "Stalwart" process has been used for protecting the inside surface of newly-laid mains in places where the original protective layer has been damaged by welding. Dutch water supplies are generally non-corrosive, and the chief difficulties arise from external corrosion from the soil.

(viii) *Switzerland.*—The waters are hard enough to build up an internal protective coating of lime and no re-lining of mains *in situ* has been carried out.

(ix) *Nigeria.*—Encrustation of cast iron mains has been a major problem. Owing, however, to the existence of a cheap labour supply, the pipes are usually taken up and re-coated with bitumen above ground and then replaced. Many miles have been treated in this way and cost about 3s. per yd. up to 6 in. diameter.

(x) *Australia—Experience of re-lined mains in service.*—Over a period of 18 years no cases have been observed by the Sydney Board where any of the cement linings applied have broken down. A number of short lengths of "inspection main" have been provided at different points. These sections of main have been jointed with "Gibault" detachable joints to facilitate removal and, after periodic examination they have been replaced and are still available for further inspection in the future. In most cases the sections examined have shown a well-applied uniform lining. A hard skin which could be lifted off in flakes had formed on the surface of the "flat" in the invert of the main. The material in the "flat" underneath this skin was, as could be expected, softer than the lining proper. In all the samples removed for inspection there were no signs of tubercles or encrustation, only a darkening of the lining surface being apparent. At the cut ends of the main section, tubercles showed some signs of growth on the unprotected metal in the joint gap. As the original marks created by the passage of the lining machine were still in evidence, no erosion of the lining had taken place during the time the main had been in service after lining. In one or two cases it was noticed that, on further inspection after an interval of five years, a thin hard skin had again formed on the surface of the "flat" from which some of the skin had been purposely removed at the time of the previous inspection.

The cost of carrying out the work of lining *in situ* can only be given approximately owing to the varying local circumstances, but it is estimated that the cost in the Sydney metropolitan area is about *one-quarter* of the average cost of providing new cement-lined main.

8. *Author's Observations and Conclusions*

(i) *"Eric" process.*—This has been widely employed in Great Britain owing to its simplicity and cheapness. Apart from a few adverse opinions it has proved a practical success, and is regarded as an economical method of extending the "useful life" of the main by 15 to 25 years.

(ii) *"Stalwart" process.*—Has had only a limited application as the company owning the patent rights failed. It is a quick and useful method of re-lining with a bitumen coating all mains above 4 in. diameter. The cost of the process is reasonable and it can be applied to larger mains rather more conveniently than the "Eric" process.

(iii) *"Tate" process.*—This process of re-lining *in situ* has been proved very successful in Australia, Uganda, Great Britain, U.S.A. and Ireland, and can now be applied satisfactorily to all mains from 3 to 24 in. in diameter. Although rather more costly than (i) and (ii) it is economically attractive and can be expected to extend the "useful life" of the main by 25 to 40 years.

(iv) *"Centriline" process* and (v) *"Preload" process.*—Both processes have been successfully developed and extensively applied in the United States of America and Canada to the re-lining *in situ* of water mains varying in diameter from 24 to 90 in. They are considered to be satisfactory in engineering technique and to be financially attractive.

(vi) *Future trend of development.*—The early difficulties encountered in applying all five processes described in this paper have now been substantially overcome. The author considers that, for reasons of engineering convenience, speed of execution and financial economy, there will be a rapid extension of the now fully proved practice of cleaning encrusted and corroded water mains and re-lining them *in situ*. The practice of applying a cement mortar lining to newly-laid large-diameter mains before bringing into service will also extend.

9. Points for Discussion

Selection of the process to be used in varying circumstances.

Economic considerations—large mains—small mains.

Present limitations of the various processes available, and desirable improvements in technique—effect of mining subsidence.

Lining materials—possible improvements in existing materials—new materials, optimum thickness of the various linings.

Hydraulic considerations.

Need for accurate flow tests, before and after cleaning and re-lining.

10. *Bibliography*

Henderson, H., The Removal of Corrosion from Water Mains, Min. Proc. I.C.E. (1893-94, Pt. II), 116, 307.

Macaulay, F. W. (1921), Pipes for Pressure Conduits, Engineering Conference of the Institution of Civil Engineers.

Smith, C. Clemesha (1903), Description of a New Pipe Scraping Machine, Trans. I.W.E., 8, 147.

Barnes, A. A., Discharge of Large Cast Iron Pipes in Relation to their Age, Min. Proc. I.C.E. (1918-19, Pt. II), 207, 28.

Barnes, A. A. (1933), Discharge of Pipes Lined with Concrete or Bitumen, Trans. I.W.E., 38, 158.

Wildsmith, A. C. (1935), Observations on the "Tate" Process of Reconditioning Corroded Water Mains in situ, Water and Water Eng., 37, 53.

Legg, A. W. (Feb., 1937), Concrete Lining of the Kampala and Jinja Water Mains by the "Tate" Process, Contractors Record.

Knudson, A. A. (1903), Corrosion of Metals by Electrolysis, Trans. Am. Electro-Chem. Soc., 3, 195.

Hayman, R. F. (1936), Corrosion, Trans. I. Chem. E., 14, 161.

Experience with a New Pipe Scraping Machine (July-Sept., 1943), Glenfield Gazette.

Dorrance, F. Y. (May, 1947), Reconditioning of Trunk Mains in the City of Montreal, Water and Sewage (U.S.A.).

Banks, W. G., and Inglee, C. (Aug., 1936), A Relined Old Main exceeds its Original Capacity, Wwks. Eng. (U.S.A.).

Twenty-four Inch Main Cement-Lined by Centrifugal Machine (Mar., 1947). Am. Wwks. Eng.

Cleaning and Cement Lining Small Mains (Mar., 1947), Am. Wwks. Eng.

Cement Lining Large Mains in Place, using Pneumatic Pressure (April, 1947), Am. Wwks. Eng.

Bailey, J. F. (1943), The Scraping of Large Water Mains, Water and Water Eng., 46, 317.

Rawlins, G. S. (Dec., 1948), Reconditioning a 24-in. Cast Iron Raw Water Main, Water and Sewage Wks., p. 435.

11. *Acknowledgments*

The author desires to make the following acknowledgments:—

The International Water Supply Association.

Engineers and other representatives of waterworks authorities in Great Britain and Northern Ireland.

The National Rapporteurs for Australia, Belgium, Canada, Eire, France, Holland, Nigeria and Switzerland.

The Eric Company Limited.

The Tate Pipelining Processes Ltd.
Messrs. John Mowlem & Co., Ltd.
The Centriline Corporation.
Preload (Great Britain), Ltd.
Mr. J. Noël Wood, of Sheffield.
Mr. H. Will Apted, of the Fylde Water Board.
Mr. S. G. Barrett, of the Newcastle and Gateshead Water Board.
Colonel F. Hibbert, of the Liverpool Corporation Waterworks.
Mr. H. Goulding and other members of the staff of the Manchester Corporation Waterworks.

MEETING ACCELERATED INDUSTRIAL DEMANDS IN SPRINGFIELD

BY PETER C. KARALEKAS*

[*Read May 19, 1955.*]

The city of Springfield is developing so rapidly industrially that the Water Works Department is hard pressed to provide additional supply conduits and distribution mains, in order to assure dependability of services at the points of industrial demand. The jump in the average demands for water from 19.1 mgd in 1940 to 30.8 in 1950 (61.5%) is almost entirely due to the growth in industrial demands, since the population during the same decade increased only 9%.

The rapid increase in the industrial demand, together with the peak demands on hot days for air conditioning, lawn sprinkling and domestic use, led the Commissioners in 1950 to undertake a program of improvements to assure full utilization of the sources of supply.

Capacity of the Supply System

The Department is fortunate in having (a) an adequate supply in the Little River sources which have a safe dependable yield of 55 mgd, even in the driest year on record; and (b) an oversized conduit which can deliver up to a rate of 100 mgd from the Cobble Mountain reservoir to the filters. Previous to 1952, the filter capacity of 32 mgd interposed a serious check on the supply rate.

Between the filters and Provin Mountain Reservoir, water can be delivered at a peak rate of 60 mgd through two steel conduits, one laid in 1909, and one laid for a distance of 13,000 ft in 1943 and extended to a total distance of 39,000 ft in 1949.

The remaining weak links in the system of supply since 1951, when the filters were increased in capacity, are the two steel conduits, extending from Provin Mountain reservoir to the city. The two conduits delivered at a peak rate of 55 mgd during the hot spell in 1953 and, as a result, pressure at City Hall was reduced to 10 lb below the normal requirement of 130 lb.

---

*Chief Water Engineer, Municipal Water Works, Springfield, Mass.

Provin Mountain Reservoir is a covered, reinforced-concrete distribution reservoir, located in Agawam. It is divided into two basins of the same depth; one holds 16.4 mil gal below overflow elevation 404.7; the other, 12.6—a total of 29 mil gal. When the reservoir is drawn down 10 ft, the usable storage is about 11.7 mil gal. In the future, when the average demand rate for several hours may rise to 80 mgd, this stored supply would suffice for 10 or 12 hours in making up the difference of 25 mgd between the inflow and the outflow rate.

Present Conduits from Provin Mountain Reservoir

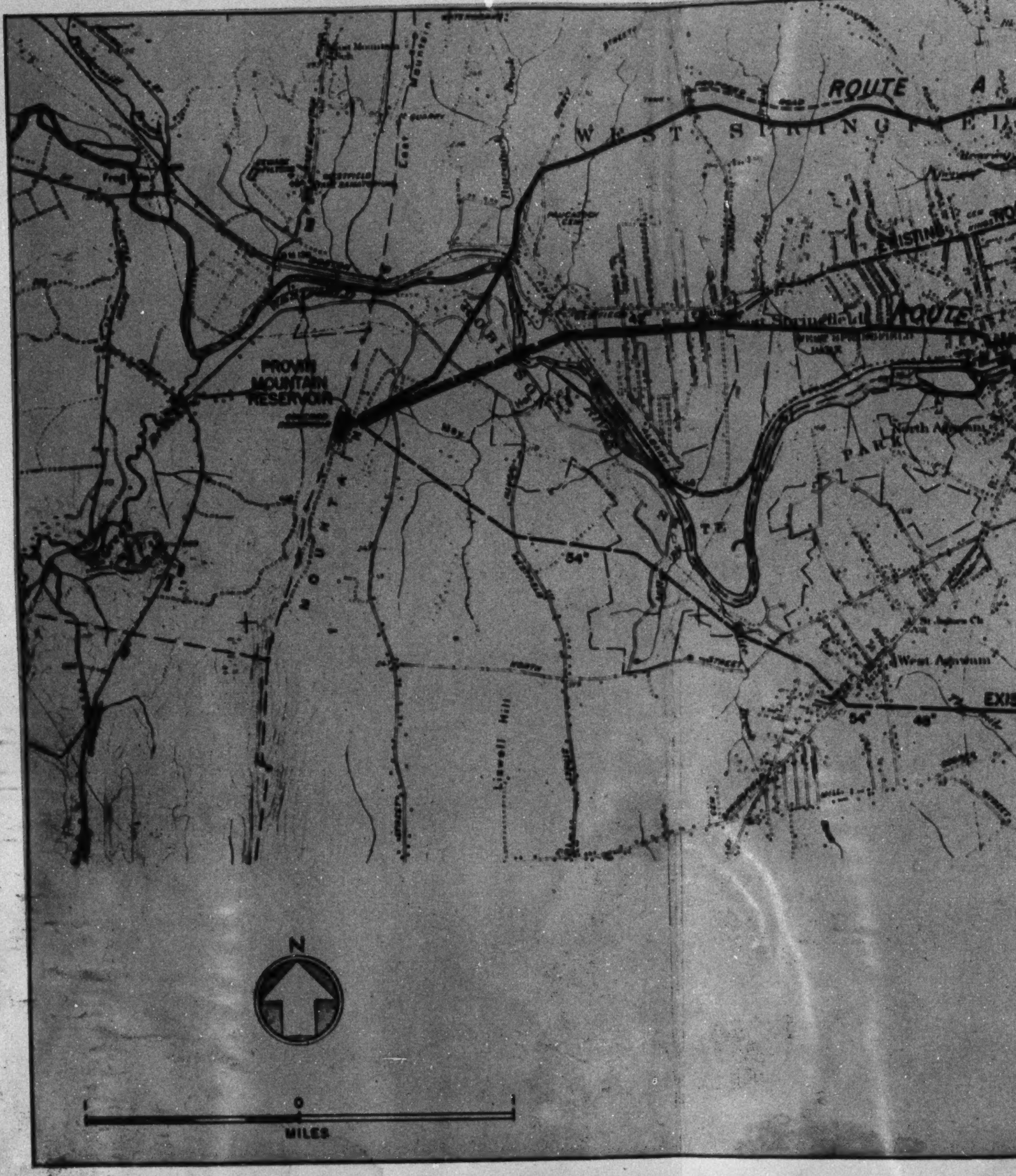
As shown on Plate 1, the conduits from Provin Mountain Reservoir traverse widely separated routes to the city. The North Conduit through the city of West Springfield is a 42-inch lock-bar steel pipe, with riveted transverse joints and a coal-tar lining. It is about 22,000 ft long and was laid in 1909. The Connecticut River is crossed by means of two 30-inch steel pipes, each about 1,100 ft long, without pile foundations. The last link, between the river-crossing pipes and the distribution system, consists of a 42-inch cast-iron pipe, 2,100 ft long.

The South Conduit through the town of Agawam is, for most of its length, nearly two miles away from the paralleling north conduit. It is 32,600 ft long, comprising 16,000 ft of 54-inch welded steel pipe and 16,600 ft of 42-inch pipe. This conduit, laid in 1929, is connected to the distribution system in the southerly part of the city, at a point 2½ miles distant from the northerly connection. The river crossing is made up of two lines of 36-inch welded steel pipes, each about 1,700 ft long.

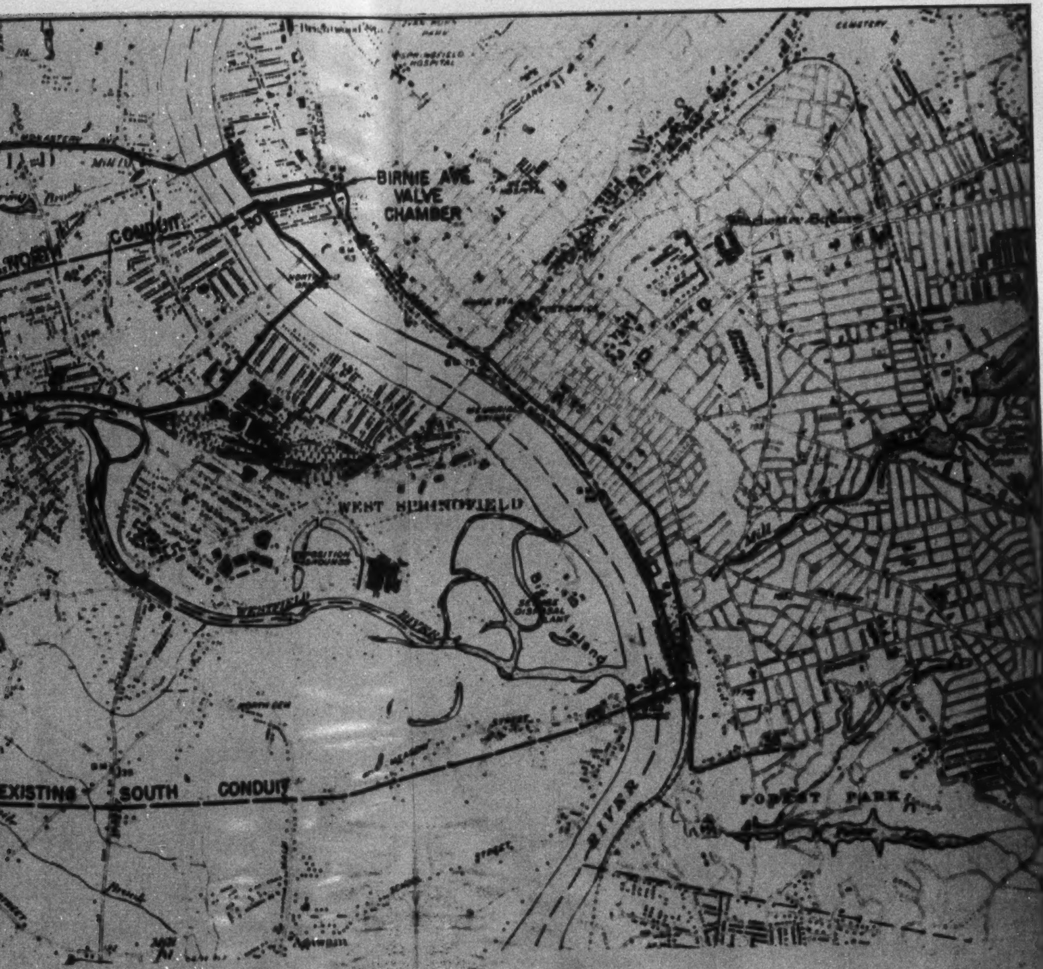
The wide separation of the conduits gives the Department security against washout of the second conduit, should a break occur in either conduit; furthermore, the wide separation of the points of discharge into the city distribution system assures better delivery pressure in the city.

Protecting the Steel Conduit

The life of a steel conduit is dependent on the degree of protection provided by its lining and by the cover on its exterior. In the


ROUTE A
WEST SPRINGFIELD
EXISTING
ROUTE
West Springfield
PROVIN MOUNTAIN RESERVOIR
PARK
North Agawam
West Agawam
EXIS
54"
48"
Liswell Hill
N
1
0
1
MILES

PLATE


BIRNIE AVE
VALVE
CHAMBER
CONDUIT
WEST SPRINGFIELD
EXPOSITION GROUNDS
EXISTING SOUTH CONDUIT
RIVER
FOREST PARK

ROUTES OF CONDUITS

BOGERT-CHILDS ENGINEERING [illegible]
CONSULTING ENGINEERS
NEW YORK, N. Y.

CITY OF SPRINGFIELD, MASS.
BOARD OF WATER COMMISSIONERS
REPORT ON THIRD PROVIN MOUNTAIN CONDUIT

ATE 1

last five years, apprehension had been growing as to the dependability of the 46-year-old north conduit. In 1926, when the north conduit was 26 years old, Chief Engineer E. E. Lochridge reported that there was "some electrolysis at points where the coating was disturbed by other construction over the pipe, but at no other point where we have had occasion to inspect it. It seems fair, therefore, to assume that the coating has been really successful." At road crossings and other possible points of electrolysis, the north conduit had a wrapped coating, which is described in *American Civil Engineers' Handbook* by Allen Hazen, who was the consulting engineer on this line:

> ". . . two to eight plies of 'Barrett Specification' felt weighing 14 to 16 lbs. per 100 sq. ft., single thickness, and 'Specification' pitch (American coal-tar pitch), 30 lbs. each mopping per 100 sq. ft. Felt was cut in strips 12 in. longer than half circumference. Pitch was mopped on top half and felt immediately applied while the pitch was hot, strips were laid shingle fashion to break joint every 16 in., for as many plies as required. After covering top half, pipe was turned over and lower half was treated in same way. Where pipe was subjected to direct currents, eight plies were used; a distance from current increased, number of plies were lessened. After pipes were riveted in trench, joints were similarly wrapped."

PROGRAM OF IMROVEMENTS

In 1951, the Commissioners initiated a series of improvements to keep ahead of the industrial demands of the city:

(1) First, the filters were enlarged at a cost of about $1,130,000, to assure a peak rate of delivery of 55 mgd. The filter improvements were the subject of a meeting of this Association in this city in May, 1953; these are described in the June issue of the *Journal, New England Water Works Association* for 1954.

(2) The second step was to strengthen the distribution system in the southern part of the city, where is situated the important Springfield arsenal works of the U. S. Army, which is one of the largest industrial users—163,000,000 gal in 1951—and customer towns. A trunk main, comprising 9,500 ft of 36-inch prestressed pipe, 7,000 ft of 24-inch cast-iron pipe, and 7,000 ft of 16-inch cast-iron pipe, was laid in 1952-3, at a cost of about $806,000.

(3) The next step was taken in 1953, when the Commissioners authorized the Northeast Distribution Main—a 36-inch, prestressed,

concrete cylinder pipe, about 6 miles long—to improve delivery to the highly-industrialized northeast section of the city, terminating at the huge works of the Monsanto Chemical Co. In this region are situated 90% of those areas in the city which are zoned for industry. This trunk main cost $1,492,000.00 and has improved pressures at Monsanto and Westover Field by 6 to 8 lb.

(4) The recent widening of Route 5 in West Springfield required the placing of considerable fill over the dual river crossings of 30-inch steel pipes on the North conduit, and directed the attention of the Department to the vulnerability of these important pipes which were laid in 1909—46 years ago—and to the consideration of means to safeguard the continuity of delivery of water from Provin Mountain Reservoir.

Report on Third Provin Mountain Conduit

Concern as to the river crossings led to a report on April 10, 1954, by Bogert-Childs Engineering Associates, in regard to the need for a third conduit, to assure adequate pressures (130 lb in the high-valve district around City Hall) in the event that:

(a) Provin Mountain reservoir is depleted 10 ft below full reservoir level;
(b) the north steel conduit is out of service for repairs;
(c) the peak rate of demand in the city is 80 mgd.

Studies of the industrial development in connection with the 1952 report on the need for the Northeast trunk main, to reinforce the system of large pipes in the city, pointed to the necessity of delivering more water to this highly concentrated industrial area, where also is located the 18-inch connection to Westover Field—a most important air-force base, using 115,000,000 gal in 1951. As shown on Plate 1, to reach the chief industrial district of the city, water from Provin Mountain Reservoir has to travel in a round-about way through the existing South conduit and the 36-inch pipe in Columbus Ave., thereby creating greater pressure losses than the shorter North conduit. This hydraulic consideration resulted in the decision to consider the proposed conduit as supplementing the North conduit, rather than the South conduit. Moreover, the North conduit has less carrying capacity than the South conduit, due to both greater age and smaller diameter.

The April, 1954, report involved the consideration of Routes A and B, as shown on Plate 1. While a part of the existing North conduit is laid in a 100-foot right-of-way in open country, a great part of it is laid in city streets, so crowded with utilities that an additional conduit, as large as 60 in., would have to be placed expensively deep, to avoid interference with sewers and house services, and would, during construction, seriously upset traffic. Therefore, it was decided to select a new right-of-way, chiefly through farm and park lands, where there would be no underground utilities and where the pipe could be laid in relatively shallow trench. Route A had the advantage of requiring less pipe in city streets than Route B.

In the 1953 hot spell, under an hourly peak flow rate of 66 mgd, pressure in the Water Department office fell to 115 lb—15 below the desirable 130. Hydraulic studies indicate that with the new line installed, Provin Mountain reservoir drawn down 10 ft, and the 42-inch line out of service, Routes A and B of the sizes shown, when delivering 80 mgd rate, would produce pressures as follows:

New line		*Pressure* (psi)		
Diameter (in.)	*Route*	*City Hall*	*Colton Street*	*Remarks*
72 and 60	A	132	63)	23,000 ft of 72″ and 7,000 ft of 60″
60	A	132	59)	
54	A	128	55)	(Existing 42″ North (conduit from Provin (Mt. considered out of (operation.
48	A	121	48)	
60	B	132	56)	
60	A	135	63)	Both existing lines from Provin Mt. considered in operation.

With the 42-inch North conduit in service, pressures would be increased 3 lb. On the basis of the above, 60 inches was the size selected. A value of 140 was used for C.

Route "A" Recommended

Route B was considered in an effort to reduce the length of easement to be acquired in West Springfield. The city owns a right-of-way 100 ft wide for a distance of 11,000 ft between Provin Mountain reservoir and Westfield Street, in which it would be possible to lay another pipe. On the other hand, however, the remainder of the route would be located in busy streets of West Springfield, where traffic, restoration of pavement, and interference with other utilities would increase greatly the cost of construction. This route would also involve a river crossing nearly 50% longer than on Route A and an additional half mile of construction of large pipe in a busy thoroughfare—Columbus Ave. in Springfield. While water would be delivered in the high-value district around Court Square at about the same pressure by Route A, the cost would be at least $400,000 greater than Route A, and time of construction six months longer.

The Proposed Conduit

Inasmuch as this new conduit will constitute the mainstay for continuity of service to the city of Springfield for many future decades, and must be as resistant as possible to the heavier street trucking loads expected years hence, it was decided to install not steel pipe, not reinforced-concrete cylinder pipe, not prestressed concrete cylinder pipe, but the newest thing in durable pipe of sizes above 48 in., resistant to heavy external loads, bombings, and electrolysis—namely, prestressed, *concrete-embedded* steel pipe. In the prestressed cylinder pipe, the circular reinforcing is prestressed against the bare steel cylinder, while in the embedded cylinder pipe, the reinforcing steel is wound prestressed against a concrete ring, outside the steel cylinder. This arrangement of the reinforcing reduces the danger of electrolysis and produces a pipe much stiffer against external loads, permitting it to be laid in a shallower trench than the old pipe, and still present equal or greater resistance to heavy truck loads.

This modern type of pipe, the 1954 report states, has the following merits:

1. Definite embodiment of the metal (both cylinder and reinforcing) in concrete safeguards against electrolysis.

2. It can withstand, without deformation, external fills several feet deeper than steel pipe of the same carrying capacity.
3. Vacuum valves are not required.
4. The dense concrete waterway assures freedom from abrasion and tuberculation.
5. The steel cylinder is adequately protected against pitting by the thick concrete on the inside and outside, while the steel spigot ring is also, to a large extent, protected by mortar, which is placed after the pipes are joined. The pipe is practically immune to damage by electrolysis.
6. The spigot ring is designed to remain tight under all conditions of service, including movement due to expansion, contraction and normal settlement.
7. Operations of installing this type of pipe are not affected by weather conditions, whereas the welding of field joints on steel pipe must be suspended in wet weather.
8. No leak has ever been reported large enough to cause failure of a section of conduit.
9. This type is available in sizes above 48 in.
10. This type requires less earth cover than steel or other types of concrete pipe to resist motor-truck loads.
11. While it is 20% heavier than cylinder pipe and more costly, laboratory tests reported to us indicate 8% higher bursting strength and 50% greater crushing strength.

Bids

Bids were received on August 31, 1954, on Contract 35, and the low bidder, Pacella Brothers Corp., was awarded the contract on a unit-price basis at $2,324,590.

The contract documents call for 1,600 linear ft of 60-inch, prestressed embedded-cylinder pipe, laid in paved streets and 23,400 ft of the same size not in paved streets; 1,600 ft of 48-inch pipe (which may be either cylinder or embedded-cylinder pipe) in streets and 310 ft not in paved streets; four 42-inch gate valves, and one 36-inch gate valve, in addition to the other usual unit items. A flow meter and recorder are to be installed at Provin Mountain.

In the city, the pipe is of 60-inch size as far as Newland St., where a Y and reducer will be inserted, and a 48-inch pipe laid to connect to the city distribution system at the Birnie Ave. valve chamber. In the near future, it is intended to continue a pipeline southward from the Y, of 36-inch size, for a distance of 5,000 ft, to connect to the existing Columbus Ave. main near the high-value district.

Rights of Way

The rights of way for the old conduits were purchased in fee simple. In the last 40 years, land values have appreciated to such an extent as to make purchase of strips 100 ft wide prohibitive. Therefore, easements 30 ft wide plus temporary easements 20 ft wide have been secured for the new line. The agreements with property owners preclude the erection of any structures above ground. Through Robinson State Park, the State would grant only a 30-foot easement. As this proved too narrow for operating the heavy equipment for a 60-inch pipe, the State granted a construction easement of 25 ft additional width. Under the contract, provision is made for new trees and grassing on both the permanent and temporary easements.

DETAILS OF THE THIRD PROVIN MOUNTAIN CONDUIT

Conduit under Railroads

The 60-inch conduit will pass under the two-track Boston and Albany Railroad in West Springfield, and the 48-inch conduit will pass under about 14 tracks in the yards of the Boston and Maine Railroad in the city. In the first case, tunneling under the railroad and the adjacent State Highway No. 20 for the 60-inch pipe will be prosecuted with liner plates, 84 in. in diameter. For the longer, 48-inch pipe crossing of the Boston and Maine Railroad yards, tunneling will be required for 100 ft, and open cut for 165 ft. Liner plates will be 78 in. in diameter. An encasing pipe of 68-inch Armco pipe is also required at this crossing by the railroad, as a safeguard against washing-out of the tracks in the event of a leak.

The crossing of the Connecticut River is controlled by the dredging requirements of the U. S. Corps of Engineers for future deepening of the river. Consideration was given to a rock tunnel, until it was proved that rock lies too far below the surface to make a rock tunnel feasible; also Bulletin 597 (1917) on the general region, by the United States Geological Survey, indicates a fault line below the river which would interpose serious obstacles to rock tunneling. The contract drawings call for the 60-inch pipe to be laid in a dredged trench on broken stone. The pipe will be of subaqueous embedded-cylinder type with special bolted joints, made up by a diver.

The Westfield River crossing of the 60-inch conduit will be supported on pile bents, spaced about 10 ft apart, with the same type of pipe as the Connecticut River crossing.

Conclusion

When this 60-inch, high-capacity collapse-proof conduit is put in service in 1956, the Water Department of the city of Springfield can, with confidence, offer improved water service, to attract new industries to Springfield and to serve better the huge defense enterprises—Westover Field and the Springfield Arsenal.

AN APPROACH TO WATER-SUPPLY TOXICOLOGY

BY BENJAMIN C. NESIN*

[*Read Sept. 20, 1955.*]

Toxicology is the science which treats of poisons, their effects, antidotes, and recognition. Many of us may not appreciate how greatly the water-supply profession is concerned with matters involving toxicity and too often are inclined to delegate such discussion to a relatively small group of isolated specialists. The disinfection of water with chlorine and the control of algae with copper sulfate are essentially toxicological processes. Our apprehension over industrial wastes on watersheds, in part at least, is concerned with the possible effects upon the health of water consumers. At the present time the implications of fluoridation and radioactive materials command our active attention because of their insidious potentialities.

Our association with the handling and control of toxic materials requires more than a passing familiarity with their nature and the perspectives attending their utilization. In this respect, we may no more absolve ourselves of such responsibility than may producers of food products, drugs, and other items of human consumption. It is true the ultimate decision in these matters does not lie with ourselves, but neither does it rest with any single group of individuals as some may suppose. The efforts of the medical profession in promoting public health would come to very little were it not for the contributions of engineers, chemists, biologists, and many others. As a matter of fact, the feasibility of most health programs and the potentialities for control are determined in very large measure by resourcefulness and ingenuities derived from many fields. This is not stated to detract from the role of the medical profession, but rather to emphasize the integration of factors necessary for the promotion of public health.

It is our business to serve as water-supply experts. In this respect our responsibilities are not mere matters of valve operation and residual testing. Water supply commands an extraordinary perspective in relation to public health. The rigors of quality control and attending factors of safety are more demanding than in other fields involving tolerances of safety. We possess a wealth of specialized knowledge and are in position to mobilize many facilities and techniques to augment such information. The significance and management of toxic potentiality related to water supply require our comprehension and cooperation. The advantages peculiar to our position would be meaningless without a fuller understanding of the objectives of the problem. In the course of this discussion voids in the knowledge related to water-supply toxicology will be evident and the potentialities for contribution from our field may suggest itself to many.

---

*Director of Laboratories, Dept. of Water Supply, Gas and Electricity, City of New York, 355 Park Place, Brooklyn 38, N. Y.

The present discussion endeavors to stress the fuller significance of toxic substances as potential factors in water-borne disease. It strives to emphasize some fundamental relationships and suggests a basis for interpretation of such factors. How does the individual consumption of water relate to the intake of toxic substances? What is the general nature of toxic reactions? How safe are the U.S.P.H.S. Drinking Water Standards? What relation do water-treatment chemicals have to toxic potentialities? These are some of the questions we are about to consider.

Variation in Individual Water Consumption

A knowledge of the amounts of water consumed by individuals is fundamental to an understanding of water-supply toxicology. That such intake is variable is commonly accepted; yet, the extent of variation and its distribution are not too well appreciated. Lacking such information it is not possible to form any conception of the intake of suspect substances accompanying the ingestion of water and articles of diet processed with water. It is surprising to find so little is actually known concerning this matter. The few studies which exist furnish some idea of the extent, but very little, indeed, concerning the distribution of such variations in populational groups.

The tissues of an adult man contain about 40 quarts of water. In the course of daily turnover between 3 1/3 and 10 quarts of the total are eliminated and must be replaced (1). The sources of water income are derived mainly from food and drink; however, metabolic processes within the body are also accountable for about 1 to 1½ quarts daily. This would indicate the range of water consumption from water supply may vary between 2 and 10 quarts daily for individual adults.

There is some evidence adduced from certain studies that the above range may be exceeded in individuals by reason of occupation, state of health, or general nature of their physical activity. Thus, Darrow & Pratt (2) note "The volume of sweat may reach 2½ liters (over 2½ quarts) an hour in men hard at work at a high environmental temperature." Moss (3) observed a maximal sweat loss of 5.8 lb per hour in a patient. Such findings would indicate bodily water losses may reach 20 quarts per day in occupations involving high temperature environments, as in metallurgical works, foundries, power plants, chemical works, laundries, etc. Another group of excessive water consumers includes those afflicted with certain ailments. Emerson (4) notes the enormous water consumption by those suffering with diabetes insipidus can exceed 20 quarts per day. A recent report concerns a case of a patient with an insatiable thirst since birth. In a hospital test her water intake was estimated at approximately 8 1/3 quarts per day. It is likely under conditions of normal activity her water intake could be considerably greater (5). In kidney-stone prophylaxis a generally recommended therapy consists of the forced intake of water for the purpose of increasing urinary volume and diluting stone-forming constituents. A consumption of at least 4 quarts daily is recommended (6), (7).

Those given to strenuous physical activity constitute another group of above-average water consumers. Athletes exemplify this group. Benedict (8) cites the case of a football player who lost about 7 quarts of water while playing during a hot afternoon. It is common knowledge among professional athletes and those whose avocations involve physical exertion that the major loss in weight in these activities is due to water of perspiration.

A review of more usual water consumption reveals that such intake may range between 2 and 8 quarts of water daily. In reporting a fluoride-balance study of 5 young men, McClure (9) presents data revealing an average consumption in excess of 3 quarts of water daily under "comfortable conditions," whereas at relatively high temperature and humidity, and with limited activity, the daily consumption rose to 5 and over 6 quarts of water. Adolph (10) presents information showing the range of minimal and liberal water loss for adult man may extend from 1½ quarts to 8 quarts per day.

While the intake of water by infants and very young children is subject to some control, since they are dependent upon caretakers for access to articles of diet, an examination of this matter reveals they they too are subject to wide variations in individual consumption. During the earliest period of life they thrive almost exclusively upon their formula. However, formula composition reveals variations in water intake ranging from 4 to over 30 ounces per day are possible and not uncommon (11). Recently, Neumann (12), in a paper before the International Association of Dental Research, analyzed the fluid intake of 312 children below the age of 7, resident in several Long Island communities. He found the bulk of daily fluid requirement was provided by milk and to a lesser degree by tap water. The combined average intake of these was 1136 cc per day, the average water intake 294 cc per day, and the overall range of water consumption for individual children varied from 1 to 25. About 45% of the children consumed water well below the average and at least 15% a quantity ranging 2 to 4 times above the average. Little variation was observed in the drinking habits from infancy to the age of 6. The writer is aware of other studies, including one being conducted by his organization, which concur quite well with Dr. Neumann's observations.

Dietz (13), while noting a somewhat higher intake in his subjects (presumably children in St. Louis), also observed its highly variable nature. Dietz, Neumann, and others, regard this as an unfavorable aspect of water-supply fluoridation.

From the foregoing it is conceivable that the range of water consumption by individual adults may extend from 1 to possibly over 20 quarts daily. The related intake by individual children may vary from a few ounces to over two quarts per day. It is evident the ingestion of suspect substances occurring in water would vary in like manner. In the light of such information it would be misleading to appraise a toxicological potential on the basis of an average assumed consumption, since this does not account for the intake of suspect substance by above-average consumers who constitute a sizable portion of the population. The assumption of an average intake is just as misleading as the assumption of an average susceptibility to toxic reaction. In the area of marginal poisoning which generally applies to water-supply situations, the affected individuals are not likely to be considered average. However, these people constitute the facts of epidemiological reality and, where entire communities are involved, this factor looms very significantly in the risks involved.

The intake of undesirable substances from sources other than water must be considered, to account more completely for the magnitude of risk involved. Such factors may include dietary customs, occupational and environmental exposures, climatic conditions, etc. Many trace elements, some reputedly toxic, others suspect, enjoy wide distribution in nature. Agricultural techniques are responsible for introducing such substances into articles of diet. The presence of trace elements, both desirable and undesirable, in foods is well known. Occupational environments impose noxious substances upon workers immediately connected with these enterprises, and may be also responsible for the introduction of such materials into community environments. The total toxicity of our environment has gradually increased with the progress of civilization. This is all the more reason to be on guard. On the other hand, there are some, who surprisingly include members of the public health field, who point to the inevitability of toxic intake as justifiable precedent for further tolerance to toxic substances. This attitude fails to take account of the apprehensive trend in environmental pollution. It also reveals a lack of understanding of the role of toxic reactions in disease processes. There is great danger implicit in such sophistry.

Nature of Toxic Action

Life processes are normally governed by an ordered arrangement of chemical and physical reactions, involving and affecting the cells which constitute all living tissues. Foreign substances, not essential to normal functioning, may enter into these reactions and hence modify normal cell activity. If such modifying action is contrary to the well-being of the host, a poisoning action is said to have taken place

(14), (15). The general nature of toxic reaction and the mechanisms involved have a similarity, whether it concerns the destruction of bacteria by chlorination, the control of algae by copper sulfate, or the poisoning of animal or human tissue by such substances as arsenic, fluoride or lead, etc.

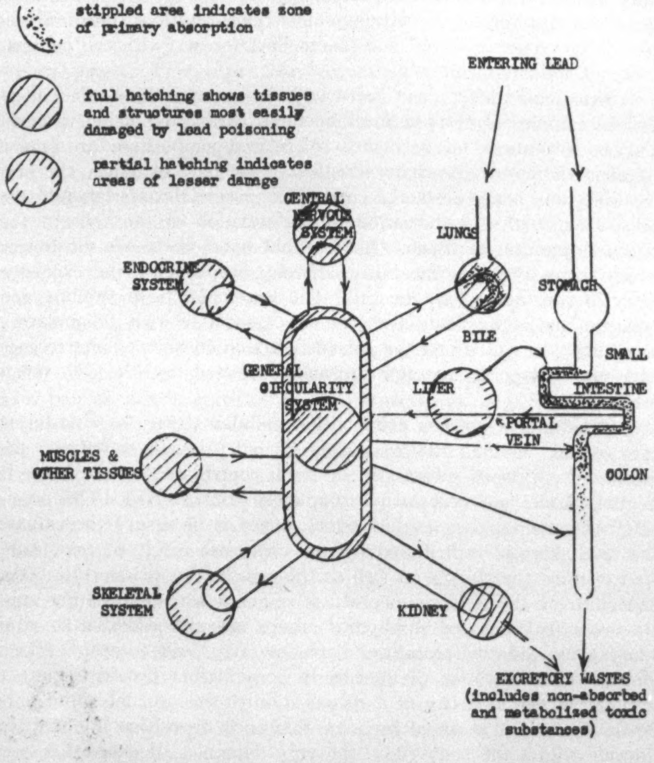
The profundities of poisonous action are best understood by a study of the effects upon the cell. The cell is a fundamentally complete unit, incorporating the basic functions characteristic of living matter. While hundreds of reactions may occur simultaneously within individual cells, interference with but a single one may result in cell damage or even its death. Some toxic agents are specific, whereas others affect numerous processes at once. There is some similarity between the overall effect of isolated potent reactions affecting the cell and poisoning which may occur within the grosser organization of the animal body. An appreciation of this may be gained from the realization that a daily absorption of 1 mgm. of lead may disaffect the mass of cells contained in a human body. Assuming the latter weighs about 150 lb, it is almost 70 million times the daily lead intake. Obviously, the action of the lead is not diffused, but rather centered in certain vital areas of the body. Nevertheless, the sensitive integration of the bodily organism provides avenues for farreaching effects.

Toxic reactions of sub-acute poisoning are subtle, insidious and, if prolonged, chronic in character. Outward manifestation to the victim, or even the physician, may not become apparent before extended exposure has occurred. This may involve a substantial portion of life span of the subject. Where exposure is unsuspected, it is unlikely the cause, or suspicion of a specific toxic effect, would be evident without extraordinary clinical investigation. Continued attack by poisonous substance may bring about a gradual accumulation of damaged tissue, akin to that observed in degenerative disease. The cumulative effects of fluoride, lead, radioactive and many other poisons in bony tissues are illustrative of such action. Thus, the condition may be confused with other chronic situations, or conceivably constitute a component contributing to the progress of disease.

In order to exert a potent effect, a poisonous substance must first gain access to the tissues. This is known as absorption. The ordinary avenues of entrance to the body are through the alimentary canal and the respiratory system. In either case, if the toxic substance is capable of absorption, it enters the circulating blood supply and is thereby transported to the various tissues of the body. A schematic representation of the paths of absorption and excretion is shown in Fig. 1. The latter, while indicating the general routes of absorption, in this instance, also shows the locations in the body more or less specifically affected by lead poisoning. Very similar schemes may be set up for arsenic, fluoride or other toxic substances.

If a reputedly toxic substance is ingested in a form or manner which renders it incapable of being absorbed, no poisonous action may be anticipated. Generally, in such instances, the toxic materials are excreted directly from the alimentary tract without passing through the bodily systems. Ordinarily, a prerequisite for absorption is that the substance be in soluble form. However, there are many complicating factors which detract from so simple a premise. There are many features of absorption which are not well understood, and there are situations where an insoluble substance may be rendered soluble, or absorbable, as a result of metabolic processes. The converse may also occur. It is quite evident that the absorption of a specific toxic substance depends upon the company it is in when ingested in the body. Thus, fluoride present in cryolite is less readily absorbed than that contained in sodium fluoride. Toxic substances taken with a full meal may prove less potent than when consumed on an empty stomach. The overall composition of water may affect the absorbability of substances contained in it. A high calcium ratio tends to depress the absorption of fluoride and lead. Since waters may vary from that resembling distilled to those of highly mineralized composition, this may be a factor influencing toxicity. It is most likely that the controversy over "natural and artificially fluoridated water" is one mainly related to the absorption factor (16), (17), (18), (19), (20), (21). The relationship of absorption to composition is an area of investigation where the contribution from the water-supply field is likely to prove of great value. In fish toxicology studies being conducted in the writer's laboratories there are strong indications that the factor of water composition may be very significant in relation to poisonous potentialities.

The layman may have a bizarre impression of poisonous action. The tendency to visualize such as a phenomenal and catastrophic event is quite common. Actually, marginal toxicity follows an insidi-


stippled area indicates zone of primary absorption
full hatching shows tissues and structures most easily damaged by lead poisoning
partial hatching indicates areas of lesser damage
ENTERING LEAD
CENTRAL NERVOUS SYSTEM
LUNGS
ENDOCRINE SYSTEM
STOMACH
BILE
SMALL INTESTINE
GENERAL CIRCULARITY SYSTEM
LIVER
PORTAL VEIN
MUSCLES & OTHER TISSUES
COLON
SKELETAL SYSTEM
KIDNEY
EXCRETORY WASTES (includes non-absorbed and metabolized toxic substances)

SCHEMATIC REPRESENTATION OF THE ABSORPTION AND EXCRETION OF LEAD

FIGURE 1.

ous "nibbling" course. Violent reactions may occur in hypersensitive and allergic individuals. In more average situations poisonous action could be limited to partial interference with bodily functions. These may include disturbances of metabolic balances, disestablishment of hormonal equilibrium, impairment of enzyme reactions, localized depletion of certain essential substances, interference with the permeability of cellular membranes, etc.

Situations which affect cell-membrane permeability offer interesting examples of toxic action associated with common phenomena. Various substances, not necessarily of related composition, are known to affect the permeable characteristics. Some tend to reduce the permeability and hence block the entrance of essential materials into the cell. This results in starvation or malnutrition of the cells of the affected organism or tissue. On the other hand, there are substances which increase the permeability, thereby encouraging the excessive entry of substances into the cell. The latter results in swelling and pressure, and is the essential mechanism associated with inflammatory conditions. In either case the poisoning action consists of interference with the balancing function normally exerted by the cell membrane (22).

Defense mechanisms exist within cellular tissue for countering toxic action. As long as detoxicating efficiency is able to outpace the income of poisonous substance, the harm contributed by the latter is minimized but not necessarily completely contraverted. The possibility of a cumulative residual effect makes it necessary to evaluate the total damage contributed by the continual insult of toxic substances upon the tissues, as well as the possibilities of overriding the capacities of the defense mechanism. Such usual detoxicating substances as calcium and sulphydral groups are also essential to vital functioning and their localized depletion may lead to very serious effects. The deposition of fluoride in bony tissues provides another example of the tendency of a detoxication process to defeat its purpose. While it is assumed by some that such deposition immobilizes fluoride within the body (23), the very dynamics of deposition is a disease process which leads to disabling and severely crippling conditions. Similar comment applies to lead, arsenic, radioactive, and other poisons, which tend to accumulate in such tissues. Also to be considered is the aspect of alteration in tissue composition with advancing age. In bones the increase in mineral contents is accompanied by a decrease of organic matrix which normally gives bones the elasticity and toughness required to resist ready fracture. The organic matrix is also essential to the proper physiological functioning of bony tissues. Increased mineralization likewise affects other tissues adversely. There are those who consider this an important factor in aging, indicative of a dying condition of the structure (24). There are those who also feel the indiscriminate ingestion of so-called essential substances has elements of danger (25). It would be unwise, therefore, summarily to assume the beneficence of defense mechanisms without further inquiry into their ultimate course.

The association between sub-acute toxicities and chronic conditions is a very important public health consideration. Chronic toxicity develops slowly with a vague beginning and may run an irregular course. Early symptoms, when present, are generally sporadic and may be confused with ordinary manifestations of malaise. The symptoms attributed to different toxic substances often show great similarity. Such frequent symptoms of lead poisoning as gastro-intestinal disturbances, loss of appetite, nausea, general weakness, backache and pains in the joints, headache, and various sensory disturbances are also common to arsenic, fluoride, and many other poisons (26), (27), (28), (29), (30), (31), (32). On the other hand, some of the markedly characteristic symptoms are often missing. The latter is demonstrated by the lesser occurrence of such symptoms of lead poisoning as the "blue gum line" in the mouth, the "stippling" of red blood cells, and the "wrist drop" (30), (33). Even the more advanced stages of chronic poisoning may not be distinguished by a unique disease. Arsenical poisoning presents so many symptoms in common that it is often difficult to delineate from lead poisoning (34). In general, digestive disturbances, anemia, general constitutional disorder, kidney disease, nervous disorders, and arthritic-like conditions are common to numerous situations involving chronic poisoning due to numerous causes.

Chronic diseases affecting the bones and related tissues are very common. Many of these are characterized as arthritic-like conditions. It is estimated about 10 million people in this country are thus ous "nibbling" course. Violent reactions may occur in hypersensitive and allergic individuals. In more average situations poisonous action could be limited to partial interference with bodily functions. These may include disturbances of metabolic balances, disestablishment of hormonal equilibrium, impairment of enzyme reactions, localized depletion of certain essential substances, interference with the permeability of cellular membranes, etc.

Situations which affect cell-membrane permeability offer interesting examples of toxic action associated with common phenomena. Various substances, not necessarily of related composition, are known to affect the permeable characteristics. Some tend to reduce the permeability and hence block the entrance of essential materials into the cell. This results in starvation or malnutrition of the cells of the affected organism or tissue. On the other hand, there are substances which increase the permeability, thereby encouraging the excessive entry of substances into the cell. The latter results in swelling and pressure, and is the essential mechanism associated with inflammatory conditions. In either case the poisoning action consists of interference with the balancing function normally exerted by the cell membrane (22).

Defense mechanisms exist within cellular tissue for countering toxic action. As long as detoxicating efficiency is able to outpace the income of poisonous substance, the harm contributed by the latter is minimized but not necessarily completely contraverted. The possibility of a cumulative residual effect makes it necessary to evaluate the total damage contributed by the continual insult of toxic substances upon the tissues, as well as the possibilities of overriding the capacities of the defense mechanism. Such usual detoxicating substances as calcium and sulphydral groups are also essential to vital functioning and their localized depletion may lead to very serious effects. The deposition of fluoride in bony tissues provides another example of the tendency of a detoxication process to defeat its purpose. While it is assumed by some that such deposition immobilizes fluoride within the body (23), the very dynamics of deposition is a disease process which leads to disabling and severely crippling conditions. Similar comment applies to lead, arsenic, radioactive, and other poisons, which tend to accumulate in such tissues. Also to be considered is the aspect of alteration in tissue composition with advancing age. In bones the increase in mineral contents is accompanied by a decrease of organic matrix which normally gives bones the elasticity and toughness required to resist ready fracture. The organic matrix is also essential to the proper physiological functioning of bony tissues. Increased mineralization likewise affects other tissues adversely. There are those who consider this an important factor in aging, indicative of a dying condition of the structure (24). There are those who also feel the indiscriminate ingestion of so-called essential substances has elements of danger (25). It would be unwise, therefore, summarily to assume the beneficence of defense mechanisms without further inquiry into their ultimate course.

The association between sub-acute toxicities and chronic conditions is a very important public health consideration. Chronic toxicity develops slowly with a vague beginning and may run an irregular course. Early symptoms, when present, are generally sporadic and may be confused with ordinary manifestations of malaise. The symptoms attributed to different toxic substances often show great similarity. Such frequent symptoms of lead poisoning as gastro-intestinal disturbances, loss of appetite, nausea, general weakness, backache and pains in the joints, headache, and various sensory disturbances are also common to arsenic, fluoride, and many other poisons (26), (27), (28), (29), (30), (31), (32). On the other hand, some of the markedly characteristic symptoms are often missing. The latter is demonstrated by the lesser occurrence of such symptoms of lead poisoning as the "blue gum line" in the mouth, the "stippling" of red blood cells, and the "wrist drop" (30), (33). Even the more advanced stages of chronic poisoning may not be distinguished by a unique disease. Arsenical poisoning presents so many symptoms in common that it is often difficult to delineate from lead poisoning (34). In general, digestive disturbances, anemia, general constitutional disorder, kidney disease, nervous disorders, and arthritic-like conditions are common to numerous situations involving chronic poisoning due to numerous causes.

Chronic diseases affecting the bones and related tissues are very common. Many of these are characterized as arthritic-like conditions. It is estimated about 10 million people in this country are thus affected. Very little is known concerning the cause and it is likely that many causes are involved. In this respect, the known association of fluoride with chronic bone change is very significant, since, if it were responsible for only a small fraction of these conditions, it would still be a matter of great importance.

Fluoride is cumulative within the body at any level of intake, even that below 1 ppm in water (23), (36), (37), (38). Since the accumulation is a function of time and dosage, it follows that the fluoride content of bones increases with age and its accumulation is promoted by an increased intake of fluoride. This establishes the dynamics for the development of damage to bony tissues. The proponents of fluoridation assume damaging bone changes are not likely to occur with water containing 1 ppm fluoride. How unlikely or how remote such occurrence may be they are unable to state, and admit to the insufficiency of investigation in this field (39). The contention of the proponents is based upon the questionable interpretation of some isolated fluoride-balance studies. On the other hand, there are others who do not concur in such opinion (35), (40), (41), (42).

Fluoride accumulation follows the course of a systemic disease, "for it attacks all bones although it has a predilection for certain places" (17). The localized rate of deposition is not necessarily uniform, and bony protrusions as well as the narrowing or sealing-up of bone spaces are known to have occurred. In extreme cases the accumulation is so extensive the bones tend to fuse together into an immobile mass. Roholm (*ibid.*) noted workers exposed in industry whose entire spines were thus affected. Since his findings other investigators have made similar observations (28), (43), (32). A British report (44) notes the fatal case of a worker so damaged after 3 years' employment in the manufacture of aluminum fluoride.

However, massive or extensive deposition of fluoride is not necessary for the production of severe pathological conditions. Slight protrusional growths which may not exceed 1/8 inch in extent, such as may occur on spinal vertebrae, often bring pressure to bear upon the spinal cord and nerve roots with pathological consequences (45), (41). Such conditions are now recognized as an established pathological and clinical entity (45). Concerning the association of fluoride poisoning with such conditions, Exner (41) states, "The similarity is, of course, obvious; and while this does not prove them the same disease, it certainly does not prove they are not". In view of the inadequate investigation of such cases and the universal and highly variable intake of fluoride by individuals, it is possible that fluoride may have been a contributing factor in some of these cases.

Threshold of Toxicity and Relation to Standards of Tolerance

It is characteristic of poisons that they do not affect everybody alike. No two individuals are exactly alike. Differences in development, hereditary factors, and many other influences invoke changes which are ultimately responsible for a wide variation in the reaction of individuals to different environmental stimuli (46). What may prove acutely toxic to some may not affect others. This disparity of effect is much more in evidence where sub-acute threshold amounts of toxic material are involved. However, this should not serve as cause to discount anticipated damage which may follow marginal poisoning, since where whole populations are concerned a seemingly slight degree of toxicity may constitute a very considerable epidemiological factor. Since water-supply exposure involves the broadest aspects of potentiality, a consideration of the minimal amount of toxic substance which may be potent is in order.

A British Commission (47) investigating arsenic poisoning reported they were unable to find out how little arsenic could produce symptoms of chronic poisoning. They found that some could tolerate doses of as much as 20 mg (As_2O_3) taken 3 times daily, whereas they noted also that a single dose of 1.3 mg was followed by alleged symptoms of poisoning.

How much non-occupational lead poisoning occurs is a matter of speculation, since this is not readily ascertained because of the similarity of symptoms with other pathologic conditions. A compilation (48) of the opinions of 40 experts revealed practically all considered a continued ingestion rate of 1.3 mgm per day dangerous. Approximately 25% thought as little as 0.325 mgm was hazardous; between these extremes there was a predominance of concurrence.

The question of minimal toxicity is important in the current discussion of fluoridation. The most manifest symptoms of fluoride poisoning are those exhibited by mottled teeth. Various findings reveal definite mottling has been associated with water supplies containing less than 1 ppm F (42), (49). Considering various sources of intake, there is some indication that a daily ingestion of 0.75 mgm F may approximate the threshold for a relatively higher incidence of more severe types of mottling (50). At 1 ppm F the incidence of definite mottling, including higher degrees of severe, many range from 10 to over 50%. Rates of ingestion of fluoride extending from 1 mgm upward daily have been associated with bone conditions generally described as osteosclerosis (17), (32), (28), (40), (44), (43). It is indicated that an intake of 3 mgm upward per day may be involved with a relatively high frequency (10%) of bony change. As with most toxic substances the lower limit of fluoride toxicity is not known, but some evidence indicates that ingestion rates as low as 1.5 mgm per day may give rise to symptoms affecting the nervous system, allergic-like reactions, and other general symptoms of malaise (35), (51), (52), (53).

There is a common tendency to accept threshold standards limiting concentrations of toxic substances tolerated in various environments with little question concerning their comprehensive significance. Since the threshold values applied to water supply are very often predicated upon experience and practice in other fields, it would be well to inquire into the comparative relationships. The information assembled in Table 1 provides a comparison of the threshold limits for arsenic, fluoride and lead in relation to their ingestion from food, water, and occupational exposures.

An examination of the above information indicates the probabilities. The following is evident in this respect:

1. The possibility of a compounded hazard due to toxic intake from a combination of sources is indicated. The comment of Cannon (55) concerning arsenic poisoning, that the majority of cases of chronic arsenic poisoning are not due to a single source but rather to the combined effects of a multiplicity of sources, may be applied to fluoride, lead, and many other toxic materials.

2. It is possible to approach or exceed the risks of occupational hazard through the consumption of toxin-laden waters conforming to the U.S.P.H.S. Drinking Water Standards. This is shown in Table 1

in the "water equivalent" column. While the water factor in arsenic poisoning may be a relatively academic consideration, the information related to fluoride and lead indicates a realistic degree of probability.

TABLE 1.—TOLERANCE LEVELS FOR ARSENIC, FLUORIDE, AND LEAD IN FOOD, WATER SUPPLY AND OCCUPATIONAL EXPOSURES. (COMPILED FROM VARIOUS SOURCES.) (54)

Toxic item	Food (ppm)	Water supply (ppm)	Occupational exposure (mgm per 8-hr day)[a]	Hazardous incidence at tolerated occup. exposure (% individuals exposed)	Water containing equivalent tolerated in occup. exposure[b]
Arsenic	3.5	0.05	0.91	—	18.2 liters/day
Fluoride	7.0	1.5	4.8	10% plus	3.2
Lead	7.0	0.10	0.72	10% plus	7.2

[a] Computed on the basis of the following tolerances (maximum allowable concentration per cubic meter of air):

Arsenic—0.25 mg As_2O_3; fluoride—1 mg (Mass. standard); lead—0.15 mg.

[b] This refers to the amount of water, containing the toxic substance at the tolerance level of the USPHS drinking water standard, equivalent to the tolerance for occupational exposure in an 8 hr. working day.

TABLE 2.—ESTIMATED RANGE OF INDIVIDUAL INTAKE OF TOXIC SUBSTANCES FROM VARIOUS SOURCES, *mgm per day*. (COMPILED FROM VARIOUS REFERENCES AND SOURCES.) (54)

Toxic item	Source Food	 Water	 Occupational exposure
Arsenic	0.1+	0.001-1.0	1.0
Fluoride	0.3-3.+	0.1-20	1-12+
Lead	0.2-2.+	0.02-6.0	0.5-20+

3. The presence in water of toxic materials common to those in occupational environments increases the hazard of workers engaged in these respective industries. Similarly, substances derived from other sources may exert an equivalent effect.

4. Water being a communal environmental factor, it is logical to assume that when it contains toxic substances in common with those present in local industrial environments, the overall effect would be not only to increase the risk of the immediate workers, but also to

increase the total number at risk in the community to the specific hazard involved.

5. It is apparent that tolerances established for food, water, and toxic substances in occupational environments are not truly standards of safety. Some measure of risk seems inevitable. It is difficult to understand the perspective which governs food standards. Since such standards were established tolerances have steadily increased, despite adverse epidemiological information. The significance of the tolerances applied to occupational hazards is more clearly understood. Apparently these tolerances consider a possible incidence of adverse effect at a level of about 10% of the workers exposed as being *insignificant*. While such qualifications may seem reasonable in occupational situations, it would most certainly be catastrophic if transferred directly to communal populations. At the standard of tolerance for lead in occupations, studies reveal (56) that 10 to 20% of the workers exposed are likely to acquire an early stage of lead poisoning, and about 2 per thousand may be afflicted with a degree of lead poisoning considered compensable under workmen's compensation regulations. Similarly, from the information available concerning fluoride toxicity in industry, it is indicated that at least 10% of the employees so exposed may develop some degree of osteosclerosis (43). The information in Table 3 indicates the relationship between fluorine exposure in occupational environments and that derived from water-supply sources in association with the incidence of osteosclerosis elucidated in a number of investigations.

6. Important differences exist between conditions of occupational and water-supply exposure, relatively unfavorable to the latter, in relation to the intake of toxic substances. Industrial exposure is limited to a rather small number of individuals who are more or less under medical observation and subject to various protective control factors. Workers in such occupations are selected; thus the weak and obviously susceptible are eliminated. Continued observation of these workers and turnover in employment results in further elimination of susceptible individuals, those revealing early signs of toxic effect, and those who find the work not to their liking. It is quite obvious, therefore, that exposure in occupation is limited to a relatively short period of life span of the average worker.

It is a quite different matter with water-supply exposure. As an environmental factor the latter holds the entire community captive—the young, the old, the strong, and the weak. Water-consumption information indicates that intakes vary widely, and case histories are a rarity. By the time an individual reaches 20 years of age he may have undergone more exposure to toxic substance than the average worker in industry. Considering variation in individual intake, the broad spectrum of individual susceptibility, the element of probability when superimposed upon the relative immensity of the populational factor, the multiplicity of sources of toxic intake, the lack of systematic clinical study, and other factors, it is difficult to escape the impression that a considerable amount of unsuspected poisoning (or illness where this factor may be contributory) does occur.

TABLE 3.—RELATION OF INGESTION, OR EXPOSURE, TO FLUORIDE IN OCCUPATIONAL ENVIRONMENTS AND VIA WATER SUPPLY, AND THE INCIDENCE OF BONE CHANGE GENERALLY DESCRIBED AS OSTEOSCLEROSIS. (COMPILED FROM VARIOUS SOURCES, INCLUDING THE ESTIMATIONS OF HODGE AND SMITH) (32), (28), (40), (43), (57).

	Source of exposure	
	Occupational	Water supply
Estimated range of daily exposure, mg	1-80	3-50
Range of low rates of ingestion, mg	1-5	2-10
Mean of low rates of ingestion, mg	3	5.8
Range of upper rates of ingestion, mg	18-80	15-50
Mean of upper rates of ingestion, mg	50	27
Range of incidence of osteosclerosis, %	25-83	11-33
Tolerated limit of exposure (based upon occupational standards), mg/day	4.8-12	—
Range of intake from water supply when fluoridated at recommended level, 1 ppm, mg/day	—	1-20

7. Fortunately few water supplies, with the exception of those obtaining fluoride, hew close to the thresholds established by the U.S.P.H.S. In general the arsenic and lead content of most waters does not exceed 0.01 and 0.05 ppm respectively. However, local situations are often encountered where the lead content may well exceed 0.1 ppm. The need for special attention to such situations should be obvious.

In general this discussion has been limited to arsenic, fluoride, and lead, since the background of investigation of these substances affords ample exemplification of the general nature of toxicity. Other toxic elements concerning which more or less is known include antimony, barium, beryllium, bismuth, cadmium, mercury, selenium, silver, tellurium, thorium and other radioactive poisons. It is obvious that most of these elements are not likely to become general factors. However, the unpredictable course of industrial pollution may give rise to unique situations. The potentialities of radioactive poisons seem generally obvious although not too well understood. At the present time beryllium poisoning has been gaining more attention, and an increasing number of clinical reports reveals the insidious character of its toxicity. The latent aspects of its poisonous effects demand an extremely careful evaluation, since disease attributable to it has been reported to occur several years after exposure has ceased. The potentialities of water-supply pollution with beryllium wastes requires careful watching.

Obviously, the number and variety of wastes which may reach water-supply sources is so great it would require a separate monograph for listing and description. Recently we have become concerned with the role of detergents. However, there are hundreds of other organic compounds and complex substances, which include many of a suspicious nature. Fortunately, most situations can be handled at the local level. However, such management requires that we continually re-evaluate our perspective, and attune our controls and treatment processes to obviate undesirable effects with a factor of safety of high order.

The Relation of Water-Treatment Chemicals to Toxicity

Of the chemicals commonly used in water treatment chlorine and fluoride are the only ones which show a likelihood of association with toxic situations. Considerable information has been presented in the foregoing discussion to qualify the toxic character of fluoride. It is the writer's opinion that no substance used in water supply has so much adverse information against it (42). The value of chlorine in the area of water purification is indisputable. Nevertheless, there can be no question of its toxic nature. Its potency is evident from its great efficiency as a germicide and specific limitations established for its control in occupational atmospheres. However, its presence in industrial atmospheres is quite a different matter from its role in water-supply purification. As an occupational hazard the pronounced effects of chlorine are initially exerted upon the respiratory system. This is tantamount to chlorination of these tissues and the obvious irritation may lead to serious respiratory ailments. The use of chlorine in water supply is another matter. The predominant effect of chlorine is upon substances present in water which are responsible, in the main, for the chlorine demand. While the reaction products may be many and unidentified, it is apparent in most situations that the bulk of chlorine dosage is converted to chloride ion, which is not toxic. We are also aware of the formation of chloramines and hypochlorite ion. The instability of the latter probably results in its further decomposition into chloride, and the recessive formation of chloro- compounds.

In the early beginnings of chlorination, chlorine was used with a sense of caution and dosages rarely exceeded a few pounds per million gallons. This situation probably prevailed for about 20 years, after which chlorine was used with increasing boldness, so that today dosages in excess of 100 lb per mil gal are not too unusual. Whereas initially chlorine was used primarily for disinfection purposes, its present role has been expanded to handle a broader scope of treatment.

These changes have occurred with virtually no attention to toxic effects which could possibly be attributable to chlorinated water. In general this lack of attention is shared by the medical profession, toxicologists in general, and other related authorities, as well as the members of the water-supply profession. In industry the public health hygienists are aware of a variety of chloro- compounds which are highly toxic and associated with chronic conditions affecting the liver and other organs (58). It is also known that many herbicides, insecticides, and other economic poisons are chloro- compounds. It would therefore be most unwise to dismiss, without further inquiry, the possible involvement of chlorination in toxicity. It may be of interest to note that work in the writer's laboratories reveals that chlorinated waters exert a differential toxic effect upon test fish long after the chlorine residual has disappeared. There is also evidence that toxic effects may be modified by the composition of the water.

It must be borne in mind that our sources of water supply are not as pure as they used to be. Encroachment upon watershed areas and wastes of industry have been responsible for much of this change. We are continually called upon to reappraise our methods of treatment and control to meet these situations. In this respect it is important to remember that our concern should not only be with the obvious. Unknown products which may be formed in the course of treatment require evaluation and this should include the toxic aspects. In evaluating chlorination it must be impressed that no one has lived through a normal life span of chlorination, much less a period involving substantial superchlorination.

For many years copper sulfate was suspect and hence quite thoroughly studied. It may not be stated that the last word concerning copper has been said. However, past investigations have virtually eliminated copper, as utilized in water-supply treatment, as a possible cause of toxic conditions. An extensive review of this subject was presented by Hale (59). This opinion is also reflected in the field of industrial hygiene. Thus, Elkins (60) states, "In its ordinary applications in industry, copper may be considered virtually harmless". In the field of human nutrition copper is regarded as one of the essential elements, and diets deficient in it may lead to certain types of anemia (61). The amount of copper ordinarily used in algae control, even where the dosage is relatively high, is generally well below the requirements considered essential for nutritional intake.

However, water-supply people are fully conscious of the toxicity of copper to lower plant life and certain forms of animal life. This demonstrates that copper is a cell poison and constitutes a basis for reservations concerning its toxicity. The writer also holds a reservation for the U.S.P.H.S. standard on copper. He is of the opinion that a dose of 3 ppm in water is objectionable because of its contributing unpalatability and other difficulties imposed by it. There can be no question of the toxicity to fish life, and in general water containing 3 ppm copper cannot be considered acceptable.

Filter alum shows a lesser degree of toxicity than copper sulfate. Actually the amount of aluminum capable of gaining access to the water-supply system represents a minute fraction of the total dosage, since the precipitation of alum floc removes all but a trace of aluminum ion. On the other hand, the absorptive properties of the aluminum coagulate may be effective in the removal of toxic substances. In general, it must be stated that the role of filter alum would more likely be concerned with detoxication of water supplies, and in all probability a similar statement may be made for other coagulants, such as the iron compounds and silica gel.

The inertness of activated carbon requires no comment here. Its reputation as an effective agent in the removal of impurities, including many of toxic nature, is too well known to warrant suspicion that it may possibly be associated with toxic effects. On the other hand, we must look forward to further studies in the utilization of activated carbon, coagulants, precipitants, and other absorptive materials for the resolution of many of the problems involving the removal of toxic substances from water. In this respect, the recent study by McCauley & Eliassen (62), concerned with the removal of radioactive strontium, is an example of such process utilizing a lime-soda technique. The investigation of treatment processes for the removal of suspect and reputedly toxic substances, and the efficiency of existing processes in this respect, is an important area of activity for the water-supply profession.

Concluding Summary

The foregoing discussion has sought to show that the presence of slight (sub-acute) quantities of toxic substances in public water supplies may be factors in disease. The known association of chronic and degenerative ailments with the continued intake of poisonous substances demands an extremely cautious approach in evaluating their tolerance in public water supplies. This is a factor we can ill afford to overlook, because of the great variance in individual susceptibility to toxic reaction and the uncertainty which exists over threshold levels of safety. Such perspective is especially timely when we are confronted with the realization that the present public health frontier concerns the conquest of chronic disease. It is likely that the insidious nature of sub-acute poisoning may not be too well appreciated. There is a tendency to take our toxic environment for granted, oblivious, or perhaps in condonation, of its potential role as a factor in disease. We show great concern over the coliform contents of our water supplies and go to great pains in suppressing and controlling this organism, even when its potential as a disease factor may be extremely remote. Yet, disease potentiality of toxic impurities may well exceed that attributable to the mere presence of coliform bacteria. It is time we re-examined our perspective in these matters.

It was emphasized in this discussion that the United States Public Health Service Drinking Water Standards are not comprehensive thresholds of safety. Toxic potentiality is not a mere matter of concentration of substance present in water. To explore the possibilities it is necessary to know how much water may be consumed by individuals, for how long, and what factors may predispose to susceptibility to toxic reaction. Our standards and factors of safety must be premised on such basis. We must not confuse tolerance with safety. A tolerable water is rarely a good water. The writer feels the goal of the water-supply profession should be to furnish a product beyond reproach for everyone in the community.

Much of the influence related to the determination of standards of water quality stems from the field of industrial hygiene. There can be no question concerning the importance of knowledge derived from experience in this field. However, water-supply men must be aware of the fact that our perspectives are different. What is considered a negligible level of hazardous incidence in occupational environments may well prove catastrophic if carried over into the water-supply environment. The factors in both situations differ greatly and the nature of the water-supply environment indicates a greater potentiality for risk. It is ever important to stress that water supply holds the entire community captive. It must also be recognized that the opportunity for compounding hazards due to intake of toxic substances from a variety of sources is another important consideration.

This discussion has utilized in the main examples from the knowledge concerning arsenic, fluoride, and lead to illustrate the nature of poisonous substances as public health factors. The principles elucidated could be very well applied to other toxic substances. However, in view of the current controversy over fluoridation it seems advisable to introduce a word of commentary based upon the author's review of the subject. The proposal for fluoridation derives, in part at least, from a tendency in therapeutics which is best described by Sollmann (63): "Medication has become more 'heroic'. The prime essential of therapy has gradually changed from the aim of 'do no harm' to that of 'do some good', even if this involves a risk, provided that the probable benefit is materially greater than the probable injury. It is justified only if the risk is fully understood. This requires a thorough knowledge of the actions of these drugs, with all the light that pharmacology can throw upon them." Concerning the basic grounds for fluoridation the following quotation from Maynard briefly sums up the status of the role of fluoride in dental caries control (25): "Fluorine occurs regularly in bones and teeth to the extent of 0.02 to 0.05 per cent. This occurrence, coupled with the benefit derived from its topical application or from fluoridated water in preventing dental caries, suggests that fluorine is a dietary essential. No one has been able, however, to produce experimentally any specific deficiency symptoms in animals from diets nearly devoid of the element, and there is no convincing evidence that the beneficial effect on teeth from its ingestion is the result of its metabolism following absorption from the digestive tract. Thus, there is no proof that fluorine is a dietary essential." It is evident that the essentiality of fluoride in the diet has not been established.

Whether the "heroic" concept of medication should be permitted to subvert the integrity of the public's water supply is a most serious question. There is no question of the poisonous nature of fluoride even when ingested in slight quantities (42). "No satisfactory reason has ever been advanced to show why everyone in a community must be compelled to endure a life-long extraordinary intake of fluoride" (50). Other more rational methods for fluoride therapy, more in accord with acknowledged medical therapeutics, are available without necessitating the exposure of entire communities to indiscriminate life-long ingestion of this toxic substance (50). Our main concern must be with the safety of the water for all, and we should be well aware of all the risks involved. Based upon such considerations, the writer is forced to conclude that the hazards associated with the ingestion of fluoride are greater than for any other substance used in water-supply treatment.

It is hoped that this discussion will stimulate further thinking and activity devoted to the evaluation of toxic substances in water supply relative to public health and the encouragement of water-quality control programs toward the interception of hazardous incidence.

BIBLIOGRAPHY—AN APPROACH TO WATER-SUPPLY TOXICOLOGY

1. Sollmann, T. Manual of Pharmacology, 7th Ed., Saunders, Phil., 1948, p. 734.
2. Darrow, D. C., and Pratt, E. L. Manual of Nutrition, 2nd Ed., AMA., 1951, p. 475.
3. Moss, K. N. Proc. Roy. Soc. London, 95 B, 181, 1923.
4. Emerson, C. P. Essentials of Medicine, Lippincott, 1919, p. 161..
5. Moehlig, R. C., and Schultz, R. C. J.A.M.A. 158: 9, 725, July 2, 1955.
6. Harlin, H. C. N. Y. State Jr. Med. Jan. 15, 1955, pp 213-220.
7. Vermooten, V. J.A.M.A. 157: 783-786, 1955.
8. Benedict, F. G. Scientific Monthly, 33, 264, 1931.
9. McClure, F. J., et al. J. Ind. Hyg. Toxicol. 27: 159-170, June, 1945.
10. Adolph, E. F. Physiol. Rev. 13, 336, 1933.
11. Spock, B. Baby and Child Care, Pocket Books, Inc., N. Y., 1951, pp. 60-61.
12. Neumann, H. H. Personal communication, May 10, 1955.
13. Dietz, V. H. J. Dentistry Children, 4th Quarter, 1954, pp. 258-261.
14. Danielli, J. F. Cell Physiology and Pharmacology, Elsevier, N. Y., 1950.
15. Oginsky, E. L., and Umbreit, W. W. Bacterial Physiology, Freeman, San Francisco, 1954, pp. 91-108.
16. Smith, M. C., and Leverton, R. M. Ind. Eng. Chem. 26, 7, 791-797, July, 1934.
17. Roholm, K. Fluorine Intoxication, Lewis, London, 1937.
18. Muhler, J. C., and Weddle, D. A. Jour. Nutrition, 55: 2, 347, Feb. 10, 1955.
19. Ranganathan, S. Ind. J. Med. Res., 29, 693, 1941.
20. Calvery, H. O. J.A.M.A., 111, 1722, 1938.
21. Tompsett, S. L. Biochem. J. 33, 1237-1240.
22. Eyring, H., and Dougherty, T. F. Amer. Scientist, 43: 3, 457-467, July, 1955.
23. Hodge, H. C. Metabolic Interrelations, Transactions 4th Conf., 1952, Josiah Macy, Jr., Foundation, N. Y., pp. 250-255.
24. Best, C. H., and Taylor, N. B. Physiological Basis of Medical Practice, 5th Ed., Williams & Wilkins, Baltimore, 1950, pp. 831-835.
25. Maynard, L. A. N. Y. State Jour. Med. 55: 9, 1312, May 1, 1955.
26. Kehoe, R. A. Lead Poisoning, Industrial Medicine (Wampler), Williams & Wilkins, Balt., 1943, p. 227.

27. Kelynack, T. N., and Kirby, W. Arsenical Poisoning in Beer Drinkers, Bailliere, Tindall & Cox, London, 1901.
28. Shortt, H. E., et al. Indian J. Med. Research 25: 553-568, Oct., 1937.
29. Sollmann, T. Ibid., pp. 804, 864-867, 874, 979-992.
30. Harris, L. J. Lead, turpentine and benzene poisoning, Arc. Int. Med., 22, 129, 1918.
31. Waldbott, G. L. Manuscript—Chronic Fluorine Intoxication from Drinking Water at the 1-p.p.m. Concentration (to be published in Inter. Archives of Allergy and Applied Immunology).
32. Linsman, J. F., and McMurray, C. A. Radiology 40: 474-484, 1943. See also erratum. Latter states, "In the paper on 'Fluoride Osteosclerosis from Drinking Water', by Major Joseph F. Linsman, M.C., and Major Crawford A. McMurray, M.C., in Radiology for May, 1943, the fluorine content of the drinking water in Spur, Texas, is unfortunately given as 12 parts per million, instead of 1.2 parts per million (Vol. 40, page 474, fifth line of second column)." Radiology, Nov., 1943, p. 497.
33. Kehoe, R. A. Ibid., pp. 218, 220, and general inform. in this chapter.
34. Sollmann, T. Ibid., p. 874.
35. Waldbott, G. L. Medical Evidence against Fluoridation of Public Water Supplies, Australian Jour. of Dentistry, Feb., 1955, pp. 13-20.
36. Boissevain, C. H., and Drea, W. F. J. Dental Research 13: 495-500, 1933.
37. Glock, G. E., Lowater, F., and Murray, M. M. Biochem. J. 35: 1235-1239, Nov., 1941.
38. Wallace-Durbin, P. J. of Dent. Res. 33: 789-800, Dec., 1954.
39. Hodge, H. C., and Smith, F. A. Fluoridation as a Public Health Measure, Amer. Assoc. Advancement Science, Wash., D. C., 1954, pp. 85, 100-101.
40. Kemp, F. H., Murray, M. M., and Wilson, D. C. The Lancet, 243, 2: 93-96 (1942).
41. Exner, F. B. Northwest Medicine, 54, 7, 721-737, Jul., 1955.
42. Nesin, B. S. Toxicity and Physiological Effects of Fluoride, Dept. of Water Supply, Gas & Elec., City of New York, 1955.
43. ————. Compiled from many sources including the following:
    a.—Agate, J. N., et al. Industrial Fluorosis, Medical Research Council Memorandum No. 22, His Majesty's Stationery Office, London, 1949.
    b.—References 16, 25, 33, 38, 39, 45 in this bibliography.
    c.—Brun, G. C., Buchwald, H., and Roholm, K. Acta Med. Stand. 106, 261 (1941).
    d.—Capizzano, N., Valotta, J., and Megy, F. R. Rev. med. y cienc. afines, 2, 19 (1940).
    e.—Dale, P. P., and McCauley, H. B. Am. Dental Assoc., 37, 131 (1948).
    f.—Khan, Y. M., and Wig, K. L. Indian Med. Gaz. 80, 429 (1945).
    g.—Kilborn, L. G., Outerbridge, T. S., and Lei, H. P. Can. Med. Assoc. J., 62, 135 (1950).
    h.—Largent, E. J., Bovard, R. G., and Heyroth, F. F. Am. J. Roentgenol. Radium Therapy, 65, 42 (1951).

i.—Pandit, C. G., Raghavachari, T. N. S., Rao, D. S., and Krishnamurti, V. Indian J. Med. Research, 28, 533 (1940).
j.—Wilkie, J. Brit. J. Radiol., 13, 213 (1940).
44. Bridge, J. C. Ann. Rept. Chief Inspector of Factories for 1939. H. M. Stationery Office, London, 1941.
45. (a) Murthi et al. J. Ind. Med. Assn. 22: 10, 396-399, July, 1953.
(b) Arnold, J. G., Jr. Annals of Surgery, 141, 6, June, 1955, pp. 872-889.
46. Karsner, H. T. Human Pathology, 7th Ed., Lippincott, Phila., 1949, pp. 11-19.
47. Monier-Williams, G. W. Trace Elements in Food, Wiley, N. Y., 1949.
48. Calvery, H. O. Ibid.
49. Exner, F. B. Testimony before Congressional Committee, N. J. Dent. Res. Assn., 1955.
50. Nesin, B. C. Various Means of Providing Fluoride Intake for Prevention of Dental Caries in Children, Dept. of Water Supply, Gas & Elec., City of New York, 1955.
51. Feltman, R. Personal communication, June 1, 1955.
52. Wolf, William. Personal communications, 1955.
53. Gutman, William. Personal communications, 1955.
54. ————. Tables 1 and 2 were compiled from the following sources of information:
a.—Federal Register, Mar. 11, 1955.
b.—Public Health Service Drinking Water Standards, 1946.
c.—Elkins, H. B. Chemistry of Industrial Toxicology, Wiley, N. Y., 1950.
d.—Industrial Medicine (Wampler), Williams & Wilkins, Balt., 1943.
(In estimating occupational exposure it was assumed the rate of inhalation of air approximates 10 liters per minute. Estimated exposure due to fluoride was premised upon the Massachusetts tolerance (1 mg per cu meter of air). Estimated intake from different sources was based upon information presented in the discussion on water intake, the experience indicated in references (c) and (d) above, the author's report on fluoride toxicity (50) and other sources.)
55. Cannon, A. B. New York State J. Med., 36, 219, 1936.
56. Bloomfield, J. J. Principles and Practice of Industrial Medicine (Wampler), Ibid., pp. 15-16.
57. Hodge and Smith. Ibid.
58. Elkins, H. B. Chemistry of Industrial Toxicology, Wiley, N. Y., 1950, Chapter IX.
59. Hale, F. E. Water Works Engineering, Jan. 28, 1942; Feb. 11, 1942; Feb. 25, 1942; Mar. 11, 1942.
60. Elkins, H. B. Ibid., p. 30.
61. Maynard, L. A. N. Y. State J. of Med., 55, 9, 1311, May 1, 1955.
62. McCauley, R. F., and Eliassen, R. JAWWA, 47, 5, 494, May, 1955.
63. Sollmann, T. Ibid., Preface to the Seventh Edition.

DISCUSSION BY RALPH M. SOULE*

The title of the preceding paper, "An Approach to Water-Supply Toxicology", may be misleading to the reader. Although various alleged toxic compounds, oftentimes found in water supplies in varying concentrations, are discussed in the paper, there is considerable emphasis on the subject of fluoridation of water supplies. Furthermore, discussions of the paper from the floor were confined to the matter of fluoridation. It is apparent that Mr. Nesin is violently opposed to the fluoridation of public water supplies. This is unfortunate, since leading physicians and dentists throughout the country, as well as national organizations well informed on the subject, endorse the program.

There are over 50 chemical compounds presently used in various forms of water treatment. Of these, none has received such public attention as to possible effects on the human body as fluoride compounds. Incidentally, it should be pointed out that most of the compounds referred to above, including filter alum, soda ash, lime, sodium hexametaphosphate and many others, are used in much greater quantities than the 1-ppm dosage recommended in fluoridation. Also, all of the compounds used in water-supply treatment are toxic in certain dosages.

The attitude of the water-works superintendent in the matter of fluoridation should be one of cooperation. He should maintain a neutral attitude on the subject and neither advocate the fluoridation of his supply nor oppose it. If his local community wishes the public water supply to be fluoridated, the approval of the local health department and the endorsement of the local dental and medical societies should be secured. In most New England states the approval of the State Health Department is required with regard to the type of equipment, fluoride compounds to be used and the point of application.

As of September 1, 1955, there were 17 communities in Massachusetts adding fluorides to the public water supply and supplying

---

* Associate Sanitary Engineer, Massachusetts Department of Public Health, State House, Boston 33, Mass.

Editor's Note: It is anticipated that additional discussions of the above paper will be received and published in a subsequent issue of the JOURNAL.

fluoridated water to a total population of about 184,000 people. The installations are inspected frequently and there has been no instance of overdosing. As is well known, the possibility of overdosing with any water-works chemical is remote and, with the supervision afforded by local water-works personnel, as well as State Health Department personnel, any overdosage would be quickly detected.

With regard to the legality of fluoridation, a review of court cases on the subject shows that the courts have found no justification for preventing the fluoridation of water supplies on the grounds of its being compulsory mass medication or irresponsible invasion of the rights of the individual.

DETERMINATION OF CHARGES FOR PUBLIC FIRE PROTECTION*

BY DARRELL A. ROOT AND THOMAS R. CAMP

Discussion by Louis E. Ayres†

It appears that the authors of this paper have recently reported to a city with a population of 12,000 on "the cost of furnishing public fire protection" (p. 100); and have "recommended . . . a value of $35,000 as being a fair charge" for this service (p. 111). Also, as a result of the studies made in connection with their report, the authors came to certain "Conclusions" (p. 113), to wit: that there were important *errors:* (1) in the classical paper of Metcalf, Kuichling and Hawley of 1911, (2) in the Joint Report of 1951 of the Committee of the American Society of Civil Engineers and associated societies, and (3) in the 1954 Water Rates Manual of the American Water Works Association. Finally the authors claim that they "have developed and presented a method of computing fire-protection charges which (they) believe to be equitable and free from basic error" and that the "cost of fire protection obtained by (their) method is substantially less than the cost computed by all other methods commonly used" (p. 113).

In view of the authors' sweeping conclusions, accompanied by their charges of error in the basic assumptions of others, their claims deserve careful scrutiny.

The principal emphasis of this paper seems to be the charge that an "erroneous assumption . . . first made by Metcalf, Kuichling and Hawley in 1911 and . . . still used by current writers" (p. 113) has led to an error of such "magnitude" (p. 93) that the authors reached the "very important conclusion which *appears not to have been recognized before,* and (which) probably has accounted for much of the confusion in thinking about equitable charges for fire protection" (p. 97) over the past 43 years (1911-1954).

---

*Published in this JOURNAL, 69:1, 90, Mar., 1955.
†Consulting Engineer, 500 Wolverine Bldg., Ann Arbor, Mich.

This "error" (p. 92) or "erroneous assumption" (pp. 93, 113) was "that the cost of a distribution system is proportional to the capacity"! The authors not only charge that three of the outstanding hydraulicians of a previous generation made such an obvious error but, having done so, left "no evidence in their paper that they were aware of having made this error" (p. 92).

It takes but a cursory inspection of the tables in the paper of Metcalf, Kuichling and Hawley to show that no such error, as is claimed by Root and Camp, was made, but that the allowances for this factor in the Kuichling computations correspond favorably with those computed by the authors. The following brief references to the Kuichling paper suffice to support this statement:

Table III, page 70, shows the "Percentage of Total Carrying Capacity of the Distribution Pipe System" required for "Fire Hydrant Service" in a system designed to furnish ***both*** "Domestic Service and Fire Hydrant Service"; and Table IV, p. 71, presents the "Relative Diameter of the Supply Main Required for Combined Domestic and Fire Service, to the Diameter of the Supply Main Required Solely for Domestic Service". An application of these tables to 10,000 population shows that with 74.1% of the capacity of a main chargeable to fire, the relative diameter of the main required for the combined service to the diameter required for domestic service is 1.718 to 1. Hence, if a 6-inch main is required for combined service, a 3½-inch main would suffice for domestic service. And referring to Root and Camp "Table 1 for populations from 250 to 12,000", a 6-inch main for combined service is reduced to 3-inch for domestic consumption only.

Also, Table VI, page 76 of the Kuichling paper, presents the "Portion of Carrying *Capacity* of Pipe System Chargeable to Fire Protection Service"; and Table XIII, page 86, column 3, shows the "Per Cent of *Cost* of Distributing Pipe System Chargeable to Fire Protection Service" under "Kuichling Standard". Again, taking a city of 10,000 population, we note from Table VI that 74% of the main *capacity* and from Table XIII that 50.3% of the main *cost* is chargeable to fire protection. Hence, the percent of the *cost* of the distribution system is *68* percent of the percent of the *capacity* chargeable to fire (68% of 74% equals 50.3%). Now turning to the authors' corresponding percentages for 12,000 population, we find that *66.7* percent of the percent of the *capacity* of 53.8 percent (p. 103) equals 35.87 percent of the cost (p. 109). And the *68%* by Kuichling is not much different from the 66.7% by the authors. If one is in error the other must be equally so.

Again, the authors refer to the Metcalf, Kuichling and Hawley formula for determining "the percent of the total fixed capital chargeable to fire protection" and state (p. 93): "If this equation is applied, the results will be much too high, *because* it is based on the erroneous assumption" above discussed. Obviously, if this equation, prepared 44 years ago, gives results that are too high today, it is not for the reason assigned by the authors, but because of other factors that enter into the result. The fire demand was computed on the basis of the "Kuichling standard" which, for 10,000 population, was 2,212 gpm, or about 70% of the 3,180 gpm required by the 1910 Standard of the National Board of Fire Underwriters used by the authors. But more important, the Kuichling computations were based on an average water use of 50 gal per capita per day for 10,000 population, and a domestic demand with fire protection of 1½ times the average domestic consumption, or 75 gal per capita per day (p. 77). In contrast with these figures, the authors use an "average flow maximum day of 125 gpcpd" and a "peak flow" (maximum hour) of twice the maximum day "for the larger populations" (p. 102), meaning 12,000.

The use of the maximum hour as a factor in determining the fire charge has been a matter of controversy since the beginning, and its use or omission makes a great difference in the result. The Underwriters have recommended the use of the "maximum consumption for any 24 hours in the past three years" plus the fire demand, as a measure of proper system capacity. Andrews in 1922 stated "that it would be going to the extreme to assume that a serious fire would occur exactly at the peak hour of the highest day"; and Pirnie in 1934 expressed the opinion that the maximum hourly demand "does not supply a figure of value in determining the proportion of the distribution system devoted to fire protection". On the other hand, Nixon, of the Public Service Commission of Wisconsin, based his computations in 1937 on the use of the "maximum hourly peak"; and the Joint Committee in 1951 used a "peak hourly demand of 2,160,000 gallons per hour . . . in a city having a population of 100,000", equal to 518.4 gal per capita per day! To illustrate the effect of using in the computations of the Joint Committee the same maximum hourly rate as that assumed by Root and Camp in their illustration, namely, 250 gal per capita per day, the percentage of "Joint Capacity Costs" in the Joint Report would have been increased from 20% to 34.2%! (p. 251).

Now come the authors of this paper, saying: "we see no reason for assuming that the maximum fire flows will occur simultaneously with peak demand" (p. 103), and yet in a following paragraph they propose a *new* method of computing the capacity chargeable to fire which is *equivalent to using a larger value* than even the peak hour. The authors' method of computation is stated as follows: "we believe that the capacity in the system chargeable to fire protection is equal to the maximum daily demand plus the maximum fire flows minus the peak demands" (maximum hour?) (p. 103). The writer is unable to follow the logic of this procedure. By its application to 12,000 population only 2,420 gpm, out of a required fire allotment of 3,460 gpm, is charged to fire. This is equivalent to using a domestic flow of nearly 1½ times the maximum hour.

But assuming that this new basis presented by the authors is sound thinking, one may consider its implications as applied to larger populations than the 12,000 used in their paper. If the authors' assumptions of "125 gpcpd" (p. 102), and a ratio of peak flow to maximum day of two, be applied to 100,000 population, the fire flow would be 9,200 gpm, plus a maximum day of 8,700 gpm, equals 17,900 gpm, less the peak flow of 17,400 gpm, leaves only 500 gpm chargeable to fire, or less than *three percent* of the total system capacity of 17,900 gpm.

Using the heretofore generally accepted method of determining this percentage for 100,000 population, by dividing the required fire flow by the fire flow plus the domestic flow, one obtains 34.6%, if the maximum *hour,* as assumed by the authors, is used. If the maximum day as used by Metcalf, Kuichling and Hawley and fire demand based on the Underwriters Standard are adopted, one finds (Table VI) 37%. And these may be contrasted with the Root and Camp figure of less than 3.0%.

The discussion of the Root and Camp paper to this point has been concerned largely with the percent of capacity and the percent of cost of the distribution system only, chargeable to fire. The capacity so chargeable with a population of 12,000, according to the authors, is "53.8% of the total" (p. 103) and the dollars so chargeable, in Table III, amount to $211,866, out of a total of $477,181, or 44.4%. Hence the percentage of the applicable pipe-line cost is only 9.4% less than the percentage of pipe-line capacity (Tables 1, 2 and 3); and this is the percentage of error (9.4%), entering into any computations which may assume "that pipe line cost is directly proportional to flow capacity". Such an "error" is certainly not an item of great "magnitude", particularly in relation to the many other assumptions that must be made in computing a fire charge on the "capacity" basis.

In addition to the distribution system, allocations must be made of the Source of Supply, Pumping and Treatment Structures and Equipment, Storage and Transmission Mains, and all of the Office, Shop and Miscellaneous Investment. The authors' allocations are presented in Table 4. The direct charges to fire are limited to the elevated tank, a stand-by pump and the hydrants. No portions, for example, of the pumping station, reservoir or purification equipment are included, although all of these facilities may be larger because of the fire demand. No two writers since the days of Metcalf, Kuichling and Hawley have agreed on the allocation of these numerous capital items, and the variations in assumptions have affected the amount of the fire charge. The authors have made another contribution to this controversy.

As to the allocations of operation and maintenance costs which have likewise varied widely with different writers, the authors present no details. One is told only (p. 111) that: "In this *particular case* the amount of operation and maintenance expense chargeable to fire protection was *determined* to be 7.70% . . . and consists of such items as maintenance of hydrants and the fire-protection portion of the undistributed overhead expense" (p. 111). And adding to this expense the "revenue which is derived from the fixed assets . . . assigned to fire protection in the percentage of 34.39 . . . the total revenue chargeable to fire protection was then determined to be 24.42% of the total revenues of the water company".

The authors then state (p. 111) that: "If we use the Metcalf, Kuichling and Hawley equation for a population of 12,000 . . . the percentage of revenue chargeable to fire protection is 36.2%", which "is in contrast to the 24.4% arrived at by our (the authors') method". Also by applying the "incremental-cost method" (p. 112) to the "capacity-ratio method", as developed by the Joint Committee, the authors claim to show two percentages, either 35.9% or 35.5% of the revenues are "to be derived from fire protection"; and "these figures are again contrasted to the 24.4% obtained by our (the authors') method". The computations upon which these percentages are based are not presented and the writer has been unable to follow the description of the methods used.

The object of the foregoing comparisons is, of course, to support the authors' conclusion (p. 113) that the "cost of fire protection obtained by their method is substantially less than the cost computed by *all other methods commonly used*".

In the opinion of the writer this conclusion rests on a precarious basis. Although the Metcalf, Kuichling and Hawley paper, written in 1911, is a classical reference on the subject of fire protection, it has been superseded for many years as a working basis, because much of the data upon which it is based do not apply today. As to the Joint Committee report, it can hardly be described as "commonly used", as it was only recently presented to the public.

Among the "methods *commonly* used" however, one may refer, for example, to those of the Wisconsin Public Service Commission. In 1937, Robert Nixon,[1] a Commissioner, presented an application of a fire charge to a community of only 4,400 population amounting to 30.5% of the total expense. The theories of apportionment of fixed capital and of operating expenses to general service and to fire protection are described and later tabulated in detail. As far as the public has been informed, the general methods outlined by Nixon are still controlling in the orders of this Commission.

A comparison of the authors' results with those prevailing in a few comparable cities in Wisconsin, as tabulated in the "Survey of Operating Data for Water Works in 1950", published in the June, 1953, Journal of the American Water Works Association, in the population range of 10,000 to 30,000, is as follows:

---

[1] Journal AWWA, Vol. 29, No. 12, p. 1837 (Dec., 1937).

Community	Population	Annual charge	Percent revenue	Per capita
Root and Camp Illustration	12,000	$35,000	24.8%	$2.92
Ashland	10,000	31,000	24.4	3.10
Two Rivers	11,000	21,400	23.1	1.94
Menasha	12,000	20,500	16.1	1.71
Waukesha	22,000	46,500	23.8	2.11
Janesville	25,000	31,500	19.3	1.26
Manitowoc	27,000	41,600	21.2	1.54
Fond du Lac	30,000	38,900	18.9	1.30

In view of the foregoing, the authors' claim, that their new "method is substantially less than the cost computed by all other methods commonly used", seems hardly warranted.

Finally, Root and Camp have rejected an alternate method proposed on pages 15 and 16 of the new Water Rates Manual of the American Water Works Association because it "is purely arbitrary and . . . has nothing to recommend it" (p. 99), and for other reasons discussed below.

The AWWA Committee on Water Rates gave considerable attention to the fire-protection charge. The so-called "capacity" basis, which has been the one in general use in the past, was thoroughly discussed and the "Basic Assumptions" for its application were presented by the writer in 1950[2] on behalf of the Committee. The incremental cost principle was adopted. The percentage of plant *capacity* chargeable to fire was based on the ratio of "fire demand" to "fire plus general service demand". However, the percentage of plant *cost* chargeable to fire protection (was to) be the percentage of *capacity* multiplied by the *ratio of increased cost to increased capacity"*, which is the primary thesis around which the authors' paper has been written and which they claim "appears not to have been recognized before" (p. 97).

The AWWA Committee recognized that the "subject of water rates (including fire charges) has been involved in controversy for several decades, and it is not possible to resolve this controversy now by any simple set of rules." The Manual, therefore, "aimed at out-lining the basic elements involved . . . and suggesting alternate rules of procedure" (p. 1). The "alternate approach to the fire protection charge involves the assumption that *storage* may be provided *in lieu of capacity*". Root and Camp now claim that the "AWWA Committee is *in error* because it assigns a storage charge in lieu of capacity" and "*in error* to charge also for the additional main capacity . . . if a storage charge is used in lieu of capacity".

---

[2] Journal AWWA, 42:990 (Nov., 1950).

The answers to the Root and Camp contentions are set forth, in part, in the Manual, pages 15 and 16. Briefly, the AWWA Committee proposed that a suitable alternative basis for a fire charge would be to include the following:

1. The cost of sufficient storage to provide the Underwriters' requirements for fire protection (Table 5).
2. The additional cost of the larger distributing mains required to deliver the water for fire *from the storages to the hydrants.*
3. The cost of all hydrants and connections, and
4. A small allowance for water used in fire fighting, at the usual rates for water.

Such a basis is relatively easy to apply and avoids the making of the many arbitrary assumptions required in the application of "capacity" basis heretofore generally used.

In the early days fire protection was accomplished by pumping from cisterns or adjacent streams and lakes. A present tendency in the design of distribution systems, particularly in larger areas, is to provide storage to meet peak demands. In the Detroit Metropolitan Area it is now a requirement in suburban service that *controlled storage* be provided in sufficient amount to equalize the maximum day. Under such conditions the water to meet the peaks and unusual demands, *including fire demands,* comes principally from storage, without any particular increase in demand on the feeder mains leading back to the source of supply, or the pumping and treatment facilities. Such storage is not at all "hypothetical" as characterized by the authors (p. 99), but actually an important element in fixing the cost of fire protection.

In summation:

1. Root and Camp are mistaken in charging Metcalf, Kuichling and Hawley with "error" (p. 92) or "erroneous assumption" (p. 113).

2. If the error charged had been made, it would have been of much less importance than claimed by the authors (p. 93).

3. The claim that the results from the application of the Metcalf, Kuichling and Hawley equation "will be much too high, *because* it is based on (an) erroneous assumption", is unfounded.

4. The authors' new method of determining the percentage of capacity chargeable to fire (p. 103) is illogical in the writer's opinion.

5. The authors' claim that "the cost of fire protection computed by (their) method is *substantially* less than the cost computed by all *other methods commonly used*" (p. 113) is not in accordance with the facts.

6. Finally, the authors' complete rejection of the "alternative approach suggested by the 1954 AWWA Committee" (p. 113) is "difficult to understand" and may well be reconsidered by them in the light of the foregoing discussion.

CLOSING DISCUSSION BY DARRELL A. ROOT AND THOMAS R. CAMP

The authors are very much pleased that Mr. Ayres has found the time to study their paper and to prepare a comprehensive written discussion. Because of his prominence as chairman of the American Water Works Association Water Rate Committee, Mr. Ayres' interest in the subject matter of our paper should serve to direct the attention of others to the important points brought out in the paper. We are greatly indebted to Mr. Ayres for succinctly pinpointing the important points of our paper in the first four paragraphs of his discussion.

The principal purpose in the publication of the authors' paper was to show that a basic mathematical error was made by Metcalf, Kuichling and Hawley in their 1911 paper without their realization, and that the same error has been perpetuated by other writers on the subject since 1911. This error is in the assumption that pipeline cost is proportional to pipeline capacity. Mr. Ayres stated that "It takes but a cursory inspection of the tables in the paper of Metcalf, Kuichling and Hawley to show that no such error . . . was made. . . ." We emphatically disagree with this statement.

The meat of the paper by Metcalf, Kuichling and Hawley consists of Curve X of Diagram 4 and the equation for this curve reproduced on p. 92 of our paper, both of which give the portion of the total fixed capital chargeable to fire protection as a function of the population served by the system. Curve X has been arbitrarily drawn by the authors of the 1911 paper with somewhat higher percentages than curves D and E, in order to take account of a slight additional cost, other than in the distribution system, in supply and reservoir systems and pumping capacity. Curve X is therefore based on Curves D and E. Each point on Curve D is the product of a per cent of the total carrying capacity required for fire protection from the Kuichling formula by the cost of the distribution system expressed as a per cent of the total cost of the water works. Similarly, each point on Curve E is the product of the per cent of the total carrying capacity required for fire protection by the NBFU by the cost of the distribution system as a per cent of the total cost of the water works. Mr. Ayres is well aware of this procedure, as shown by the example in the seventh paragraph of his discussion. This procedure is erroneous because the cost of the distribution piping is not proportional to the capacity, and the capacity percentage is not interchangeable with the corresponding cost percentage. The percentage of the cost of the pipes chargeable to fire protection should have been used in the multiplication instead of the percentage of the capacities chargeable to fire protection.

To illustrate this point, consider the flows required for a population of 12,000 as illustrated at the bottom of p. 103. The fire flow plus maximum daily demand required for the existing system is 4,500 gpm, whereas the peak flow required of a similar system without fire protection is 2,080 gpm. Let us suppose that the existing system requires a supply main consisting of 20-in. pipe. Since the peak flow for the hypothetical distribution system without fire protection is only 47% of the maximum required for the existing system, the required pipe size is 75% of 20 in. or 15 in. The nearest commercial size, or 16-in., would be used. From Fig. 1 of our paper, the cost of the 16-in. cast-iron pipe is shown to be about 72% of that of 20-in. pipe. The additional cost of this item for fire protection is thus about 39%, whereas the additional capacity is 53.8%. It is evident that 53.8% is not a satisfactory substitute for 39%.

In Mr. Ayres' seventh paragraph, he endeavors to prove that no error has been made in the Metcalf, Kuichling and Hawley paper by showing that approximately the same result may be obtained by the Kuichling formula as the authors obtained in their example. This is a completely fortuitous circumstance and has nothing to do with the basic principles.

In Mr. Ayres' paragraph 10, he states that he is unable to follow the logic of our statement that "We believe that the capacity in the system chargeable to fire protection is equal to the maximum daily demand plus the maximum fire flow minus the peak demand." He has answered his own question in paragraph 9 of his discussion, in which he states that "The underwriters have recommended the use of the maximum consumption for any 24 hours in the past three years plus the fire demand as a measure of the proper system capacity." The proper system capacity for the hypothetical system without fire protection is obviously the peak hourly demand. Hence, the increment of capacity chargeable to fire protection is the difference between these two figures.

If in the authors' Fig. 2, the lines for peak flow and fire flow plus average flow maximum day are projected off the figure until they intersect, the point of intersection corresponds with a population of about 200,000. In other words, for a city whose population is in excess of 200,000, with demands similar to those of the authors' example, there will be no incremental charge for fire protection on all works serving more than 200,000 persons. This would include the reservoir intake and supply mains, and possibly some arteries in the distribution system. In another case studied by the authors, involving a system serving about 150,000 persons, it was found that there would be no incremental charge for fire protection on supply mains and arteries serving more than 110,000 persons. In this latter system with very long supply mains a large part of the cost of the pipelines was in these large mains. This is one reason for our statement that "The cost of fire protection obtained by our method is substantially less than the cost computed by all other methods commonly used."

Mr. Ayres in his paragraphs 11 and 12 arrives at substantially the same conclusion by applying our method to a city of 100,000. He finds to his surprise that for this example less than 3% of the cost of the supply works is chargeable to fire protection, but he apparently has not grasped the significance of this trend for cities of larger populations.

Mr. Ayres complains in his paragraph 14 of our failure to include the pumping station and reservoir among the facilities chargeable, at least in part, to fire protection, because, as he states, all of these facilities may be larger because of the fire demand. The fact of the matter is that these portions of the system were investigated, as set forth on p. 110, and none of them was found to be larger because of the fire demand. Hence, none of their cost is chargeable to fire protection. On the other hand, a new elevated tank was constructed solely for the purpose of improving fire protection. Hence, all of the cost of this tank is chargeable against fire protection.

In Mr. Ayres' paragraphs 19 to 21, he presents examples resulting from computations with the method used by the Wisconsin Public Service Commission as proof that methods commonly used do not result in higher costs for fire protection, as we claim. A study of the 1937 reference cited by Mr. Ayres reveals that Nixon also assumed that distribution-main cost is proportional to capacity. It follows that if he had not made this false assumption, his figures for the cost of fire protection would have been less.

In Mr. Ayres' paragraph 23 he endeavors to explain the method recommended by the AWWA Committee on Water Rates. This committee stated that it had adopted the incremental cost principle. The method of computation explained by Mr. Ayres in his paragraph 23 is certainly not the incremental cost principle, and the logic upon which it is based is difficult to understand. This procedure is certainly not the method which we recommend and is in no way similar to it. What we claim "appears not to have been recognized before" is the fact that all three methods defined on p. 97 of our paper give the same results, if the same flows are used and costs are assumed to be proportional to capacity, but that the results are vastly different if costs are not assumed to be in proportion to capacity and are actually estimated.

An examination of the paper by Metcalf, Kuichling and Hawley reveals that these authors were aware of the fact that the cost of pipelines is not proportional to capacity. On pp. 69 and 70 of their paper, may be found the following: "It is also possible to determine the ratio D/d of the diameters of two supply mains, one of which (D) is adapted to carrying the combined fire and domestic and industrial supply while the other (d) is capable of delivering only the domestic and industrial supply, both pipes having the same hydraulic gradient. Under a given grade, the pipe discharge varies as the five halves power of the diameter. If the cost of the pipe per lineal foot is expressed in terms of the diameter, the difference in the cost of the two lines may be computed . . .".

It is evident that these authors toyed with the idea of proceeding as we have done. They did go far enough to compute the ratios of the diameters which are shown in their Table IV. No further use was made of these ratios in computing costs, however, although in the footnote to Table IV the implication is left that the figures in Table IV have been used in making their final figures. Despite this start in the right direction, they finally used the assumption that pipeline cost is proportional to capacity. We have found no evidence in their paper that they were aware of having made this error or of the magnitude of the error involved. This error appears not to have been discovered by any of the numerous discussers of the paper by Metcalf, Kuichling and Hawley, and it appears not to have been understood by current writers on the subject, as has been so amply demonstrated by Mr. Ayres' discussion.

MEMOIR OF ARTHUR C. KING

Arthur C. King, former Superintendent of the Taunton Water Works and a Past President of the New England Water Works Association, passed away on March 4, 1956. He is survived by his wife, two daughters and a son.

Born in Taunton, Mass., on April 5, 1884, he was the son of George A. and Florence W. (Dean) King.

In 1906 he was graduated from Brown University with a B.S. degree in Civil Engineering. The summer before and the year following his graduation he was employed as an Engineering Assistant with the Massachusetts Department of Public Health. In 1907 he became a Transitman and Inspector with the Springfield Water Works and worked on the construction of the intake and purification works of the Little River Water Supply. Later he became an Assistant to the Superintendent and was in charge of service construction and maintenance, and underground records. Mr. King then, in 1919, worked as an Estimator for the Lockwood Greene Co. and was connected with design of the sewerage and water systems for Yorkship Village in New York.

After a short term of employment as a Chief of Survey Party, he became an Engineer for the Mount Hope Finishing Co. and, in that capacity, designed and supervised construction of the water system and much of the general street layout of the town of North Dighton, Mass.

In 1924 he became Assistant Superintendent of the Taunton Water Works and served as such for 8 years until the death of his father, Superintendent George A. King, also a Past President of the New England Water Works Association. At that time he was appointed Superintendent and Clerk of the Board, serving until his retirement in 1954. His efforts while Superintendent largely made possible the distribution reservoir and modern pumping station which are now near completion.

Active in both professional and civic organizations, Mr. King held membership in the New England Water Works Association for 49 years and was President during 1948-1949. His other professional societies included the American Society of Civil Engineers and the Boston Society of Civil Engineers.

The Boy Scouts of America were probably his favorite activity. He worked vigorously in their behalf and served for many years as President or a Director of the Anawan Council, B. S. of A. Other activities included Kiwanis, Past President and District Lieutenant Governor; Dighton Rock Grange, Past Master; and the Masons.

Those of us who had the privilege of knowing Arthur King will long remember him as a true gentleman. His Boy Scout leadership typifies the willingness with which he gave of his time and ability, both professionally and in private life. We all mourn his passing with deepest regret.

THOMAS B. WILLIAMS, JR.

MEMOIR OF HARRY U. FULLER

Harry U. Fuller was born in Camden, Maine, on December 3, 1877, the son of Harry G. and Harriet Rogers Fuller. He was educated in the grade schools of Camden, and later, when the family came to Portland, he attended Portland High School.

As a young man, he served with the Engineering and Public Works Department of the city of Portland. He was also the engineer for the firm of Sawyer and Moulton, and later served as engineer for the Androscoggin Reservoir Co. His work on roads, bridges and dams throughout Maine gave him a wide practical experience in bringing the forces and knowledge of nature to the benefit of mankind.

Mr. Fuller came to the Portland Water District in 1915. At that time, the District was making its first extension of mains into territory which had never before been served, and he was the first engineer to be employed by the District in that capacity. During his service of more than 33 years with the Portland Water District, he surveyed all the new territory which was served with water and superintended the construction of the new conduit in 1925, and the 48″ concrete main route, installed in two sections.

During his work with the District, Mr. Fuller was allowed by the Trustees to take time to do consultation work for several municipalities. He designed the water system for the town of Gray and did all the engineering work. He also did work for the Wilton Water Co. In 1938 Mr. Fuller located and designed the system of wells at North Windham, which are still in use.

He retired from his service in 1949 and died on March 6, 1956.

He was a member of the Maine Association of Engineers and a charter member of the Maine Water Utilities Association. He was an honorary member and past president of the New England Water Works Association, and a former member of the American Water Works Association. He was a former member of the Portland Rotary Club.

As a personality, Harry Fuller was perfect for his vocation: tall, handsome, and with a fine, easy manner. He was helpful to his fellow men and loyal to his employers, as well as a kind and devoted husband.

F. J. Reny

REPORT OF COMMITTEE ON RAINFALL AND YIELD OF DRAINAGE AREAS

RAINFALL IN NEW ENGLAND*

PART IV. RAINFALL IN VERMONT

BARRE, VT.
Record: January, 1941, to December, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1941	1.45	2.05	2.64	0.51	2.48	2.99	6.15	4.37	1.22	3.25	2.09	1.91	31.11
1942	1.66	2.00	4.12	3.11	2.10	4.97	1.09	1.64	4.76	3.62	3.44	3.07	35.58
1943	1.08	1.70	1.78	2.32	3.76	3.79	3.47	4.36	1.78	4.57	4.42	0.82	33.88
1944	1.70	2.31	1.26	3.24	1.63	4.30	2.69	1.56	3.99	3.50	1.98	2.35	30.51
1945	4.00	1.59	1.53	4.13	6.38	2.29	4.89	2.82	6.11	4.63	3.48	1.84	43.69
1946	2.33	2.55	1.07	1.73	3.78	2.21	2.43	7.50	3.34	3.86	2.15	3.79	36.74
1947	3.44	2.54	2.05	1.09	4.39	5.87	3.51	0.74	2.47	0.63	3.65	1.21	31.59
1948	1.75	1.19	2.12	1.78	4.11	4.17	3.53	4.18	0.93	2.72	4.87	2.84	34.19
1949	1.98	2.34	2.08	3.04	2.31	2.10	3.32	3.68	2.51	1.77	2.97	1.83	29.93
1950	3.15	2.45	3.34	1.90	1.46	3.43	1.77	3.04	2.47	2.11	4.15	2.80	32.07
Av. 10 yrs.	2.25	2.07	2.20	2.28	3.24	3.61	3.28	3.39	2.96	3.07	3.32	2.25	33.92

BELLOWS FALLS, VT.—Elevation 300 feet
Record: November, 1902, to December, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1942	2.21	2.60	5.17	1.99	4.41	2.81	4.23	1.74	2.80	2.25	5.63	4.82	40.66
1943	2.51	1.66	2.45	3.25	5.09	1.41	3.29	5.19	1.42	4.70	6.39	0.43	37.79
1944	1.88	2.74	3.23	3.65	1.56	5.15	3.63	1.93	4.56	2.24	2.18	2.34	35.09
1945	4.27	2.88	1.69	5.44	6.86	6.03	4.80	1.11	4.16	2.82	5.19	3.47	48.72
1946	3.37	2.87	1.08	2.42	7.28	2.36	2.90	2.91	3.67	2.21	1.94	4.41	37.42
1947	3.65	2.83	3.93	2.81	4.11	4.88	5.14	1.87	1.51	1.14	6.65	2.83	41.35
1948	3.23	2.22	3.06	3.39	6.03	4.27	2.50	1.20	0.44	2.16	6.34	3.37	38.21
1949	3.69	3.09	2.29	3.27	4.35	1.44	4.32	4.44	4.26	2.02	2.81	1.74	37.72
1950	4.10	3.04	3.37	3.00	2.35	3.79	2.74	5.87	4.12	2.04	5.71	3.32	43.45
Av. 40 yrs.	2.89	2.46	3.02	3.41	3.25	3.55	3.80	3.14	3.33	2.55	3.45	2.76	37.61

BENNINGTON, VT.—Elevation 720 feet
Record: January, 1897, to September, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1942	1.51	1.44	4.72	2.16	3.91	2.81	6.92	3.21	4.01	3.42	4.62	3.92	42.65
1943	1.96	1.47	2.67	4.74	7.02	3.02	4.10	5.29	2.06	3.63	6.54	0.67	43.17
1944	1.61	1.46	3.10	3.95	1.60	4.62	4.80	2.25	6.24	2.45	4.17	1.74	37.99
1945	2.79	2.04	1.35	6.04	6.58	7.20	6.01	2.72	4.49	4.46	5.50	1.70	50.88
Av. 25 yrs.	2.39	2.14	2.96	3.02	3.34	3.97	4.85	3.51	3.70	3.09	3.78	2.31	39.06
1946	1.79	2.96	1.54	2.15	6.88	—	3.46	4.09	4.74	3.51	1.57	—	—
1947													
1948	2.89	1.91	—	3.94	—	6.27	2.54	2.89	1.56	—	4.91	6.63	—
1949	2.73	0.78	—	3.18	1.49	1.54	4.93	2.80	—	—	—	—	—
1950	3.26	2.34	2.01	2.73	—	5.48	3.07	7.91	2.75	—	—	—	—

---

*Continued from this JOURNAL 70:1, 91, March, 1956.

BLOOMFIELD, VT.—Elevation 900 feet
Record: August, 1906, to December, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1942	1.96	1.98	3.59	3.14	2.97	5.05	1.59	3.36	4.33	2.88	4.21	2.59	37.65
1943	0.88	2.20	1.68	2.81	3.08	8.18	3.38	6.00	3.36	4.20	5.74	1.29	42.80
1944	1.44	4.19	1.94	2.48	2.31	3.13	5.48	2.80	4.43	4.19	2.94	2.03	37.34
1945	4.04	1.95	1.69	3.75	5.42	3.85	5.10	3.32	7.58	4.81	3.45	3.02	47.98
1946	2.19	1.85	1.32	2.03	3.45	2.66	3.11	5.58	4.57	3.71	3.08	3.24	36.79
1947	3.28	2.44	1.88	1.73	7.10	4.32	9.14	1.46	2.82	1.55	3.95	1.40	41.07
1948	1.71	1.63	2.11	2.54	5.11	4.10	1.69	4.59	1.75	2.13	5.26	2.73	35.35
1949	2.40	2.34	2.28	2.64	4.06	2.77	3.10	3.04	3.70	2.73	2.73	2.72	34.51
1950	3.36	1.38	3.05	2.85	1.62	5.90	2.42	6.33	2.20	2.87	6.52	3.26	41.76
Av. 44 yrs.	2.34	1.97	2.35	2.94	3.29	3.95	4.31	3.85	4.16	3.61	3.23	2.43	38.43

BURLINGTON, VT.—Elevation 404 feet
Record: 1828; 1832; 1833; July, 1837, to December, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1942	1.43	1.45	2.89	3.08	2.13	6.36	2.21	4.19	4.97	3.21	1.65	2.99	36.56
1943	0.92	1.11	1.25	2.24	4.35	4.12	4.48	4.84	1.71	3.82	3.29	0.51	32.64
1944	1.77	2.53	1.37	3.22	1.75	4.06	3.63	2.76	3.85	8.56	1.96	1.36	30.82
1945	2.97	0.82	1.91	3.84	5.90	2.93	4.57	1.84	8.18	4.55	3.45	1.17	42.13
1946	1.53	1.84	1.39	2.31	4.03	1.57	3.89	4.32	3.45	4.35	3.76	2.16	34.57
1947	3.51	1.42	1.70	1.39	5.05	4.84	4.90	1.83	2.50	0.88	3.20	1.12	32.34
1948	1.41	1.01	1.99	2.94	3.03	2.88	4.54	3.41	0.87	2.51	5.17	2.53	32.29
1949	2.09	2.08	1.40	2.34	1.58	1.09	4.70	4.42	2.64	1.46	2.62	1.80	28.22
1950	2.42	1.31	2.79	1.52	1.58	2.38	2.41	3.90	2.45	1.61	4.36	4.10	30.83
Av. 116 yrs.	1.84	1.62	2.07	2.21	3.01	3.44	3.84	3.33	3.48	3.18	2.60	1.94	32.56

CANAAN, VT.
Record: January, 1941, to December, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1941	1.53	0.80	1.76	1.01	3.22	3.35	3.90	3.24	2.49	3.71	2.78	1.77	29.56
1942	1.44	2.35	3.31	2.54	2.67	5.81	2.41	2.41	4.71	3.08	3.58	2.53	36.84
1943	0.93	2.31	1.70	2.37	3.66	10.22	3.88	4.79	4.15	3.76	4.17	1.15	43.09
1944	1.29	2.34	1.44	2.30	1.88	3.49	2.12	4.52	5.05	4.72	2.04	2.19	33.30
1945	4.12	2.30	1.86	3.54	4.89	2.60	6.17	1.63	7.72	3.84	2.61	2.32	43.60
1946	2.72	2.57	1.54	2.62	3.25	2.69	3.55	3.88	2.30	5.18	3.56	3.77	37.63
1947	3.30	2.43	2.20	2.17	6.70	3.86	5.46	1.36	5.48	2.01	3.84	1.33	40.16
1948	1.52	1.93	2.31	2.37	4.89	1.60	2.68	3.21	1.41	1.80	5.53	2.76	32.01
1949	2.49	2.24	2.69	2.50	3.63	4.45	2.97	3.02	2.57	2.50	2.99	2.89	34.94
1950	4.18	1.93	2.78	2.74	1.26	5.70	2.13	4.74	2.14	2.21	4.99	2.67	37.47
Av. 10 yrs.	2.35	2.12	2.16	2.42	3.60	4.38	3.53	3.28	3.80	3.28	3.61	2.34	36.86

CAVENDISH, VT.—Elevation 910 feet
Record: February, 1903, to December, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1942	2.51	2.80	4.44	2.90	4.00	5.19	3.92	1.83	4.51	2.54	4.17	4.69	43.50
1943	2.63	2.11	2.54	4.07	6.40	3.13	5.79	5.23	2.15	4.94	4.93	0.69	44.61
1944	1.61	2.93	4.32	3.24	2.07	5.90	2.19	0.99	4.42	3.03	2.86	2.10	35.46
1945	3.44	4.16	1.55	5.27	7.33	4.40	6.34	0.67	3.97	4.25	5.71	2.95	50.04
1946	3.02	3.17	1.49	2.02	4.29	2.35	4.31	2.74	4.56	2.40	1.92	4.56	36.83
1947	3.59	2.48	4.52	2.86	4.91	5.78	5.40	3.05	1.15	0.49	5.85	2.69	42.77
1948	3.75	3.10	2.86	3.98	4.40	3.98	4.21	1.59	1.18	2.55	5.73	5.09	42.42
1949	4.60	2.49	1.92	4.03	3.24	3.08	3.27	2.05	5.33	2.31	2.92	1.61	36.85
1950	4.86	3.66	4.51	2.54	2.77	2.50	1.86	3.25	2.73	2.82	5.49	3.59	40.58
Av. 47 yrs.	3.03	2.70	3.09	3.34	3.47	3.76	4.25	3.11	3.69	3.05	3.53	2.92	39.94

CHELSEA, VT.—Elevation 840 feet
Record: January, 1886, to December, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1942	1.75	1.69	3.63	2.82	4.23	5.80	2.10	0.74	5.61	2.78	3.49	2.89	37.53
1943	1.12	1.21	1.53	2.49	4.97	5.98	5.16	5.09	1.87	5.62	3.71	0.56	39.31
1944	1.31	2.49	2.12	3.21	1.72	5.33	4.29	1.17	4.49	3.80	3.08	1.69	34.70
1945	3.22	2.33	1.30	5.13	6.67	5.47	4.99	1.47	6.77	5.54	4.16	2.06	49.11
1946	2.21	2.36	1.12	1.82	3.55	3.60	4.73	6.81	4.80	2.88	2.13	3.58	39.59
1947	3.39	2.01	2.43	1.71	5.37	8.06	6.56	1.78	1.33	0.97	4.79	1.52	39.92
1948	2.39	1.85	2.31	2.25	4.14	2.15	5.63	2.89	0.74	2.40	5.47	2.98	35.20
1949	2.77	1.99	—	2.99	2.39	2.19	4.59	3.92	2.90	2.09	2.25	1.91	—
1950	3.62	2.22	2.76	2.27	1.67	2.37	2.42	3.67	3.59	2.29	4.51	2.84	34.23
Av. 63 yrs.	2.67	2.41	2.78	2.76	3.13	3.51	3.63	3.36	3.45	2.91	3.15	2.49	36.25

CORNWALL, VT.—Elevation 517 feet
Record: January, 1887, to October, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1942	2.13	—	—	2.51	1.83	4.16	1.48	1.17	5.11	3.06	2.90	—	—
1943	—	—	—	—	3.64	4.46	3.58	4.87	2.35	5.00	3.50	—	—
1944	—	—	—	3.78	2.48	2.78	4.83	1.10	5.20	3.39	—	—	—
1945	—	—	—	—	—	—	—	—	—	—	—	—	—
1946	2.20	—	1.06	1.75	3.91	3.30	5.13	5.27	3.83	2.75	1.95	—	—
1947	—	—	—	—	—	—	—	—	—	—	—	—	—
1948	—	—	—	2.34	3.99	3.94	4.74	6.60	1.33	2.00	4.70	4.15	—
1949	2.62	—	1.78	1.83	1.74	1.10	3.04	6.30	4.11	—	2.69	—	—
1950	1.92	—	—	0.95	1.16	3.09	3.23	4.76	1.73	1.02	—	—	—
Av. 51 yrs.	2.12	1.94	2.09	2.18	2.78	3.44	3.53	3.19	3.17	2.69	2.58	2.10	31.81

CRAFTSBURY COMMON, VT.—Elevation 1,250 feet
Record: August, 1935, to December, 1945

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1942	2.09	2.75	4.67	4.29	3.26	5.91	2.50	1.88	4.53	3.84	3.94	3.72	43.38
1943	1.25	2.95	2.74	3.98	4.12	6.63	3.29	6.06	2.19	4.07	4.62	1.73	43.63
1944	2.25	2.92	2.21	3.61	2.13	4.98	5.08	1.62	5.94	3.37	2.48	2.06	38.65
1945	4.29	2.58	2.20	5.24	6.48	4.54	7.79	1.70	9.67	7.65	4.46	3.05	59.65
Av. 9 yrs.	2.36	2.46	2.99	3.61	3.93	4.61	3.86	3.08	4.78	4.24	3.22	2.94	42.08

DORSET, VT.
Record: January, 1941, to December, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1941	1.39	1.38	1.50	0.50	2.02	5.74	4.93	3.18	4.15	4.92	2.81	3.32	35.84
1942	1.74	2.53	4.17	3.05	3.87	6.84	3.58	2.04	4.84	3.46	4.21	4.22	44.55
1943	3.00	2.69	3.21	4.62	7.32	3.51	6.52	6.94	2.05	4.35	5.68	0.85	50.74
1944	1.42	1.59	4.88	3.58	4.45	5.60	3.30	1.19	3.40	2.69	2.22	2.59	36.91
1945	4.26	—	1.82	7.34	5.43	4.72	7.51	1.73	5.24	6.30	5.47	1.33	—
1946	2.70	2.80	1.62	2.62	6.15	2.92	3.35	3.57	6.96	4.48	2.41	3.03	42.61
1947	3.50	2.07	4.88	4.30	5.64	7.02	5.47	0.95	1.03	0.58	3.01	1.86	40.40
1948	2.45	3.09	3.79	4.60	5.23	4.77	5.02	3.14	1.25	2.01	6.34	8.02	49.71
1949	5.34	2.09	2.42	3.89	3.92	1.32	9.25	3.89	3.13	3.27	2.77	3.38	44.67
1950	4.23	3.42	3.88	3.11	2.52	4.56	5.19	4.83	3.03	2.01	7.10	2.01	45.89
Av. 9 yrs.	2.87	2.41	3.37	3.36	4.57	4.70	5.18	3.30	3.32	3.09	4.06	3.25	43.48

EAST BARNET, VT. (Fifteen Mile Falls)
Record: July, 1929, to December, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1942	1.42	1.75	4.42	3.26	3.31	4.57	0.89	0.68	5.16	3.13	3.83	2.18	34.60
1943	1.06	1.50	1.82	2.68	3.95	4.37	3.10	5.50	2.19	4.69	4.36	0.85	36.07
1944	1.76	2.14	1.74	3.17	1.64	4.86	3.07	2.33	4.13	3.73	1.85	1.93	32.35
1945	3.75	1.98	1.57	4.88	5.99	4.32	5.19	1.07	7.68	4.20	3.62	2.74	46.99
1946	2.66	2.37	1.24	1.85	3.95	2.26	2.38	5.79	3.16	4.61	2.56	3.57	36.40
1947	3.58	1.82	1.77	1.58	5.75	8.35	6.72	1.37	0.98	1.17	3.48	1.38	37.95
1948	2.14	1.48	2.14	1.62	3.83	3.75	2.02	3.48	0.93	2.96	5.70	2.37	32.42
1949	2.14	2.22	1.42	2.34	3.61	2.60	2.70	4.40	3.23	2.12	2.85	2.43	32.06
1950	3.28	1.98	2.45	2.79	1.48	4.01	2.15	4.66	2.51	2.60	3.95	3.08	34.94
Av. 21 yrs.	2.41	1.68	2.20	2.74	3.24	3.65	3.68	3.10	3.46	3.00	3.09	2.32	34.56

EAST RYEGATE, VT.—Elevation 480 feet
Record: January, 1914, to June, 1949

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1942	1.22	1.58	3.60	2.64	3.82	4.03	0.82	0.64	4.81	2.98	4.23	2.34	32.71
1943	1.25	1.59	1.56	2.67	3.29	4.07	3.71	4.42	1.32	4.36	4.34	0.99	33.57
1944	1.25	2.30	1.57	2.99	1.53	3.75	3.85	1.63	4.02	3.51	1.86	2.19	30.45
1945	4.01	1.82	1.23	4.36	5.38	3.24	6.27	2.11	6.03	4.14	3.18	—	—
Av. 32 yrs.	2.06	1.88	2.30	2.83	2.60	3.33	3.77	3.17	3.13	3.11	2.82	2.11	33.11
1948	2.38	1.25	1.29	1.70	3.60	—	—	—	—	—	—	—	—
1949	1.94	1.84	1.41	1.59	3.48	2.46	—	—	—	—	—	—	—

ENOSBURG FALLS, VT.—Elevation 601 feet
Record: June, 1891, to December, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1942	1.11	1.90	3.82	3.98	3.27	5.64	2.56	6.14	2.98	3.70	2.74	2.10	40.03
1943	—	—	—	—	—	—	—	—	—	—	—	—	—
1944	—	—	—	—	—	—	—	—	—	—	—	—	—
1945	—	—	—	—	—	—	—	—	—	—	—	—	—
1946	—	—	—	—	—	—	—	—	—	—	—	—	—
1947	3.02	2.32	2.39	2.04	8.41	6.33	8.42	2.14	5.52	1.04	4.02	1.03	46.68
1948	1.07	1.80	2.97	4.26	3.65	2.12	4.32	3.17	1.40	2.26	6.50	4.14	37.66
1949	4.26	2.57	3.72	3.26	3.03	2.59	3.11	6.12	3.15	2.67	3.57	2.69	40.74
1950	2.42	1.83	2.63	3.05	1.57	4.56	3.99	7.60	2.59	2.96	5.78	4.36	43.34
Av. 52 yrs.	2.46	2.24	2.83	2.91	3.57	4.29	4.59	3.68	3.86	3.61	3.48	2.70	40.22

ESSEX JUNCTION, VT.
Record: January, 1942, to December, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1942	0.77	1.33	2.84	3.12	2.44	6.22	2.16	—	5.18	3.75	2.03	2.52	—
1943	0.65	1.00	1.10	1.90	5.08	4.30	4.20	5.98	2.21	3.98	4.61	0.20	35.21
1944	1.55	3.00	1.21	3.50	1.49	4.32	3.43	2.80	4.29	3.16	1.68	2.30	32.73
1945	3.26	—	1.48	4.54	6.29	—	5.13	1.44	8.46	5.36	3.80	0.96	—
1946	1.60	1.97	1.46	2.70	4.04	1.58	4.15	4.53	3.16	5.87	4.07	2.74	37.87
1947	3.63	2.35	1.42	0.75	—	5.07	5.01	1.55	3.67	0.87	3.13	1.09	—
1948	1.22	0.89	2.10	2.42	4.46	3.01	3.81	4.32	1.24	2.82	5.66	1.56	33.51
1949	2.14	—	1.51	1.86	1.62	1.73	3.88	5.15	2.93	1.58	2.88	1.62	—
1950	2.36	1.30	2.74	1.52	1.07	2.71	1.49	4.75	3.15	1.95	2.85	3.54	29.43

GILMAN, VT.—Elevation 850 feet
Record: March, 1927, to November, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1942	1.28	1.01	2.60	2.57	2.69	4.93	1.60	0.63	4.83	2.45	3.41	1.81	29.81
1943	0.70	—	1.60	2.99	—	5.32	2.68	5.32	2.13	3.93	4.88	0.89	—
1944	1.30	1.35	2.42	2.55	2.35	5.36	5.42	2.58	4.35	3.77	2.14	2.18	35.77
1945	—	1.81	1.50	4.08	6.06	3.65	3.90	1.52	7.73	3.92	3.13	2.80	—
Av. 14 yrs.	2.25	1.48	2.65	2.79	2.99	3.81	3.78	2.82	3.95	2.56	2.81	2.17	34.05
1946	2.57	1.57	—	1.90	3.95	2.33	1.92	5.27	4.12	2.23	2.44	2.85	—
1947	3.40	1.73	—	1.81	4.82	6.63	5.71	2.79	1.26	0.71	3.12	—	—
1948	1.30	—	1.85	1.71	4.59	—	1.82	3.11	1.68	2.44	5.06	—	—
1949	1.78	—	—	1.75	—	1.87	—	—	2.68	—	—	1.98	—
1950	—	1.08	1.37	2.26	—	3.99	2.10	2.50	0.93	2.40	3.68	—	—

GRAFTON, VT.
Record: January, 1940, to December, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1940	1.87	2.75	3.78	5.22	5.72	4.18	2.58	1.52	5.03	0.71	5.55	3.72	42.63
1941	1.56	2.89	1.28	—	—	—	4.35	2.68	1.63	2.31	3.38	4.07	—
1942	2.73	2.32	4.63	2.25	3.74	3.27	—	1.12	—	2.28	4.42	3.32	—
1943	2.12	1.98	2.58	—	6.29	1.92	4.00	5.37	1.22	4.77	5.16	0.64	—
1944	1.47	2.55	3.82	—	1.16	6.22	3.79	0.82	5.02	2.69	2.86	2.95	—
1945	3.04	3.37	1.46	5.27	6.45	5.20	4.71	0.90	3.41	3.11	4.62	2.89	44.43
1946	—	—	4.12	2.19	5.94	3.61	3.61	2.54	4.62	1.59	1.70	4.54	—
1947	3.69	2.19	4.09	2.83	—	4.35	3.62	2.00	1.19	0.66	4.90	2.31	—
1948	2.32	2.69	2.70	3.46	4.23	3.45	—	1.99	0.35	1.77	5.99	5.74	—
1949	4.73	2.26	1.69	3.03	2.72	0.69	3.45	2.69	3.29	1.96	2.27	1.82	30.60
1950	5.11	3.61	4.37	—	2.13	1.92	1.61	5.88	2.27	2.31	4.53	3.56	—

LYMAN FALLS, VT.
Record: January, 1940, to December, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1940	0.65	1.75	3.46	2.43	4.80	4.02	4.44	2.30	3.78	1.37	5.23	2.21	36.36
1941	1.26	1.25	1.30	0.82	2.74	1.51	4.79	2.88	2.14	3.84	2.19	2.03	26.75
1942	2.17	1.83	3.50	2.79	2.56	4.41	1.46	3.15	3.99	2.63	3.58	2.97	35.04
1943	0.98	2.38	2.13	3.23	2.34	7.99	3.46	5.58	3.21	4.01	6.53	1.29	43.13
1944	1.53	2.23	2.17	2.25	2.34	2.78	5.31	2.69	4.34	4.18	3.19	2.19	35.20
1945	—	3.89	1.58	3.81	5.01	3.63	4.79	3.08	7.18	4.63	3.43	3.31	—
1946	2.56	2.22	1.48	2.05	3.28	2.50	3.05	5.21	4.65	3.37	3.03	3.72	37.12
1947	3.94	2.67	2.20	1.88	7.01	4.15	8.89	1.39	2.73	1.51	3.76	1.50	41.63
1948	2.01	1.85	2.13	3.36	4.03	3.66	1.63	4.29	1.60	1.92	5.14	2.92	34.54
1949	2.21	2.21	2.26	2.35	3.61	2.48	2.84	2.46	3.07	—	—	—	—
1950	—	—	—	2.62	1.52	5.15	3.38	5.59	1.32	2.58	5.68	3.05	—
Av. 8 yrs.	1.89	2.02	2.30	2.35	3.64	3.88	4.13	3.44	3.30	2.85	4.08	2.35	36.23

MARSHFIELD, VT.
Record: January, 1942, to November, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1942	1.46	1.70	4.43	3.27	2.56	5.88	2.58	3.05	4.21	3.54	3.65	3.68	40.01
1943	1.37	2.15	2.08	2.61	4.17	5.15	4.08	4.77	2.04	4.34	4.29	1.26	38.31
1944	1.71	2.01	1.52	2.71	1.95	5.52	3.38	2.94	4.65	3.52	1.49	2.39	33.73
1945	2.79	1.64	1.88	5.33	6.32	3.04	5.41	1.19	6.98	5.95	3.49	1.59	45.61
1946	2.34	2.62	1.26	2.12	4.99	2.71	4.05	7.04	3.75	3.65	2.75	4.58	41.86
1947	3.40	2.52	2.05	1.64	4.96	6.98	4.93	2.00	1.74	0.68	4.14	1.53	36.57
1948	1.77	1.62	2.20	1.87	4.05	4.89	3.59	4.22	—	3.49	5.27	2.92	—
1949	2.47	2.53	1.82	4.38	3.36	2.14	—	8.03	—	2.42	3.02	2.56	—
1950	2.97	—	2.99	2.81	1.20	4.63	—	3.40	2.37	1.88	3.45	—	—
Av. 6 yrs.	2.18	2.11	2.20	2.95	4.16	4.88	4.06	3.50	3.90	3.61	3.30	2.50	39.35

MAYS MILLS, VT. (Halifax)—Elevation 900 feet
Record: January, 1914, to December, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1942	2.61	3.56	6.96	1.78	6.87	3.71	7.06	1.47	6.44	3.79	6.91	6.12	57.28
1943	3.64	2.23	3.63	4.49	7.00	2.59	6.52	3.25	2.41	6.20	6.00	0.66	48.62
1944	2.06	3.04	6.38	5.06	1.40	6.78	4.35	1.74	6.31	2.02	3.82	4.65	47.61
1945	4.48	5.12	2.07	6.88	9.18	7.28	8.63	2.37	3.30	3.75	4.55	3.51	61.12
1946	3.35	4.01	1.40	2.61	6.91	5.70	3.62	4.38	5.05	2.70	1.54	6.31	47.58
1947	4.08	3.18	4.78	4.62	6.06	4.71	4.55	4.94	2.78	1.34	6.35	3.08	50.47
1948	3.74	3.82	4.43	3.39	9.37	5.34	2.18	1.48	0.47	2.10	6.34	6.19	48.85
1949	6.72	3.50	3.29	5.53	4.21	1.26	3.55	5.17	4.48	2.64	2.74	3.22	46.31
1950	6.62	5.77	5.23	3.35	4.72	3.40	3.29	5.22	3.11	2.68	6.73	5.35	55.47
Av. 37 yrs.	3.90	3.51	3.85	3.82	4.18	3.87	4.14	3.83	4.02	3.12	4.39	3.76	46.40

McINDOE FALLS, VT.
Record: April, 1932, to December, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1942	1.25	1.35	3.81	3.11	4.31	4.88	1.25	0.81	5.24	3.10	4.16	2.47	35.74
1943	1.28	1.46	1.59	2.74	3.64	5.11	3.37	4.25	1.74	4.32	4.39	0.81	34.70
1944	1.40	2.06	1.66	3.29	1.73	4.62	3.50	1.66	3.62	3.58	1.78	2.22	31.14
1945	3.72	1.50	1.42	5.40	6.54	4.46	7.64	1.69	6.97	5.20	3.93	2.93	51.40
1946	2.35	2.72	1.35	1.98	3.87	2.26	2.45	7.56	3.35	4.83	2.68	3.66	39.06
1947	3.24	1.43	1.59	1.35	6.37	5.64	7.18	2.34	0.98	1.55	3.73	1.44	36.84
1948	2.31	1.22	2.13	2.71	4.59	2.78	2.84	3.23	1.02	3.04	6.66	2.38	34.91
1949	2.52	1.86	1.42	2.27	4.09	2.71	3.40	4.25	1.73	2.63	3.24	2.52	32.64
1950	2.73	1.79	2.75	2.71	1.89	4.54	2.42	5.93	2.22	2.47	4.32	3.12	36.89
Av. 18 yrs.	2.26	1.65	2.13	2.91	3.64	3.73	3.97	3.37	3.40	3.29	3.42	2.38	36.15

MIDDLESEX, VT.
Record: January, 1942, to December, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1942	1.54	1.83	3.40	3.21	2.56	4.43	2.25	1.44	4.81	3.85	2.84	3.58	35.74
1943	1.01	1.91	1.79	2.35	4.70	3.90	3.81	4.87	2.79	4.86	3.73	0.58	36.30
1944	1.55	2.13	1.35	3.39	2.20	3.89	2.86	1.87	4.37	2.85	1.34	2.33	30.13
1945	2.91	1.84	1.79	4.73	6.58	2.85	8.17	2.64	7.25	6.15	3.28	1.52	49.71
1946	1.89	2.10	1.51	1.77	5.02	2.28	3.08	4.45	2.98	4.35	2.97	3.99	36.39
1947	3.16	2.01	2.26	1.43	6.55	7.51	5.91	1.62	2.26	1.18	3.81	1.23	38.93
1948	1.73	1.38	2.05	2.08	4.03	3.61	4.49	4.77	1.41	2.82	4.80	3.36	36.53
1949	1.76	2.26	1.85	3.54	1.79	1.28	5.66	4.10	2.40	1.76	2.73	1.90	31.03
1950	2.80	2.03	2.75	1.57	1.28	3.34	3.33	5.37	2.87	2.69	3.45	3.24	34.72
Av. 9 yrs.	2.04	1.94	2.08	2.67	3.86	3.68	4.40	3.46	3.46	3.39	3.22	2.41	36.61

MONTPELIER, VT.
Record: January, 1942, to December, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1942	1.67	1.81	4.06	2.59	2.04	5.04	1.07	1.75	3.94	3.75	3.60	2.97	34.29
1943	1.05	1.50	1.66	1.87	3.82	3.97	3.87	4.34	1.72	5.05	4.03	0.87	33.75
1944	2.28	2.81	1.44	3.21	1.76	4.35	3.40	2.35	4.84	3.36	2.02	1.67	33.49
1945	2.64	1.38	1.66	4.12	5.24	2.46	3.47	2.53	5.65	4.95	3.19	1.41	38.70
1946	1.71	1.84	0.98	1.43	3.67	1.81	1.66	4.40	4.17	2.43	2.13	5.32	31.55
1947	—	—	—	—	—	—	—	—	1.91	0.81	1.98	1.76	—
1948	3.37	2.22	2.88	2.85	2.97	2.84	3.65	5.85	0.82	2.24	4.84	3.00	37.53
1949	2.84	2.35	1.93	3.40	2.61	2.01	4.11	4.18	2.19	1.85	2.84	2.14	32.45
1950	3.01	2.30	3.67	2.23	1.67	3.96	2.26	3.54	2.16	2.41	4.38	3.45	35.04
Av. 8 yrs.	2.32	2.03	2.28	2.71	2.97	3.30	2.94	3.62	3.19	3.26	3.38	2.60	34.60

MORRISVILLE, VT.
Record: November, 1941, to December, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1941	—	—	—	—	—	—	—	—	—	—	2.37	2.54	—
1942	2.36	1.37	3.51	2.79	2.91	6.55	2.55	2.74	5.02	3.15	3.71	3.42	40.08
1943	0.97	2.04	2.15	3.07	3.73	7.67	3.16	4.48	2.11	4.81	4.24	—	—
1944	2.21	2.51	1.36	2.77	2.28	4.18	4.01	2.11	5.47	2.96	2.15	2.08	34.09
1945	3.23	1.48	1.94	4.36	5.38	3.82	4.96	1.14	9.38	5.61	3.87	1.97	47.14
1946	2.50	2.16	1.36	2.03	3.91	3.55	2.91	5.06	3.82	4.17	3.76	4.58	39.81
1947	4.03	—	—	2.34	4.69	4.43	4.00	1.98	2.30	1.31	3.67	1.48	—
1948	1.75	1.99	2.32	3.17	3.14	—	3.47	3.60	1.51	3.09	5.54	3.73	—
1949	—	2.28	2.34	2.99	1.97	2.13	3.34	3.88	1.71	1.90	2.24	2.65	—
1950	3.99	2.26	2.74	2.01	1.04	2.62	2.21	6.80	1.84	2.15	3.31	3.76	34.73
Av. 5 yrs.	2.86	1.96	2.18	2.79	3.10	4.14	3.33	3.57	5.11	3.61	3.36	3.16	39.17

NEWFANE, VT.—See TOWNSHEND, VT.

NEWPORT, VT.—Elevation 700 feet
Record: 1884 to December, 1950 (broken)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1942	1.52	3.31	4.58	2.88	2.03	5.68	2.40	2.96	4.96	3.74	3.01	1.52	38.59
1943	0.75	1.84	1.24	3.15	3.17	5.41	3.66	4.94	1.98	3.41	5.80	0.88	36.23
1944	1.23	1.84	0.97	2.57	1.20	4.11	4.37	—	—	—	1.98	1.49	—
1945	3.63	1.61	2.29	4.20	5.08	1.50	5.09	2.24	8.48	5.35	3.73	1.77	44.97
1946	2.39	2.24	1.24	2.70	3.87	2.03	2.38	4.27	4.53	3.89	3.31	4.04	36.89
1947	3.56	2.69	1.69	2.36	5.69	4.66	6.31	1.82	5.30	1.19	3.34	1.43	40.04
1948	1.14	1.85	2.07	3.60	3.86	3.18	2.51	3.62	1.76	2.60	5.67	3.31	35.17
1949	2.19	2.22	2.39	2.21	1.95	3.33	3.61	5.05	2.02	2.17	2.98	3.02	33.14
1950	3.84	1.59	2.90	2.52	1.30	5.83	2.75	5.00	1.63	2.19	3.95	3.05	36.55
Av. 12 yrs.	2.91	2.41	2.93	3.37	3.84	4.38	4.52	4.01	4.64	3.43	3.92	2.84	43.20

NORTHFIELD, VT.—Elevation 876 feet
Record: March, 1887, to December, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1942	2.28	1.55	4.01	2.91	1.93	5.02	1.41	1.34	4.93	3.29	3.15	3.43	35.25
1943	1.18	1.70	1.76	2.90	4.03	4.47	3.45	4.22	1.62	4.95	5.92	1.29	37.49
1944	1.78	3.14	2.01	3.33	1.61	5.06	5.13	1.57	4.21	3.08	2.46	2.01	35.39
1945	3.79	2.17	1.83	3.69	5.93	2.91	3.77	3.25	7.69	5.13	3.68	1.97	45.81
1946	1.76	2.36	1.32	1.77	3.93	2.32	2.38	5.51	4.22	3.11	2.49	3.74	34.91
1947	3.57	1.98	2.66	0.97	4.69	7.14	6.46	2.15	1.41	1.02	4.75	1.55	38.35
1948	2.27	1.31	2.20	1.72	4.39	2.82	3.17	4.34	1.55	2.46	4.72	3.26	34.21
1949	1.84	1.84	1.40	2.72	3.21	2.15	4.77	3.85	2.29	1.67	2.83	1.30	29.87
1950	3.22	2.01	3.13	1.59	1.54	3.72	2.71	2.79	2.32	2.03	3.59	2.99	31.64
Av. 63 yrs.	2.27	2.06	2.49	2.42	2.87	3.30	3.46	3.35	3.09	2.72	2.89	2.30	33.22

READSBORO, VT.—Elevation 1,220 feet
Record: January, 1915, to December, 1923; January, 1932, to December, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1942	2.56	2.92	5.79	2.20	4.56	2.87	6.70	1.60	4.71	3.36	5.64	4.33	47.24
1943	3.15	2.09	3.19	4.32	7.67	3.58	4.34	4.85	1.13	5.31	5.80	0.62	46.05
1944	1.24	2.60	5.12	4.59	1.52	6.43	4.82	3.06	5.24	2.56	3.19	4.92	45.29
1945	4.41	4.69	1.65	7.25	7.16	5.58	5.98	2.61	3.59	3.79	4.75	2.61	54.07
1946	2.76	4.16	1.86	2.79	7.11	4.27	4.80	3.10	5.35	3.05	1.98	5.54	46.77
1947	4.66	2.08	6.68	5.33	6.59	5.59	8.01	3.15	2.57	1.51	5.20	3.01	54.38
1948	2.96	3.53	3.90	4.82	8.06	5.97	2.65	2.49	1.03	1.63	6.59	7.73	51.36
1949	7.03	3.28	2.48	4.54	4.32	2.86	2.94	4.36	4.67	2.40	2.40	3.24	44.52
1950	6.15	4.75	3.79	2.93	4.70	3.69	4.57	4.94	4.69	2.53	6.94	4.34	54.02
Av. 28 yrs.	3.88	3.11	3.86	4.15	4.52	4.43	4.42	4.01	4.34	3.41	4.24	3.84	48.21

ROCHESTER, VT.—Elevation 850 feet
Record: January, 1929, to December, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1942	2.43	3.16	5.51	3.08	2.80	3.40	1.80	1.57	4.21	3.75	4.39	3.43	39.53
1943	1.52	4.17	2.40	3.20	6.61	4.43	7.04	6.32	2.58	4.71	5.25	1.90	50.13
1944	2.10	3.07	4.34	4.98	1.95	5.15	4.07	1.53	5.31	4.04	1.19	2.61	40.34
1945	4.92	2.73	2.73	6.12	5.09	6.32	7.75	0.75	9.63	6.70	4.77	2.23	59.74
1946	2.88	3.52	—	2.43	4.90	3.50	4.03	5.79	3.76	4.74	3.12	5.18	—
1947	3.75	1.16	5.25	2.58	5.35	9.28	4.34	3.09	1.13	1.03	4.85	2.37	44.18
1948	2.41	2.60	4.35	2.86	4.42	2.82	4.76	4.32	0.90	2.48	5.89	6.09	43.90
1949	2.95	3.51	2.48	4.54	3.11	2.00	4.74	3.54	3.35	—	3.05	3.74	—
1950	5.17	3.18	—	2.85	1.79	4.46	1.83	3.78	3.75	1.70	5.87	3.02	—
Av. 19 yrs.	3.10	2.52	3.54	3.66	4.13	4.06	4.71	3.51	4.00	3.31	3.75	3.05	43.34

RUTLAND, VT.—Elevation 568 feet
Record: January, 1917, to December, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1942	1.40	1.30	3.42	2.13	3.63	5.41	2.64	1.14	4.44	4.09	2.61	2.34	34.55
1943	1.93	1.62	1.77	2.62	5.40	4.46	7.42	5.88	2.66	3.26	4.41	0.69	42.12
1944	1.47	2.34	2.61	3.17	2.26	5.47	4.84	0.84	4.27	3.81	2.46	1.69	35.23
1945	3.86	2.05	1.86	5.93	4.24	4.55	9.65	0.78	6.63	5.75	3.83	1.46	50.59
1946	1.54	2.51	1.53	2.32	5.14	3.60	3.63	3.96	5.31	3.10	2.08	2.78	37.50
1947	3.33	1.87	4.30	1.72	4.49	6.40	4.41	0.79	1.05	0.86	3.80	1.83	34.85
1948	2.16	2.26	2.58	2.97	4.43	2.45	3.57	2.84	0.71	2.43	4.98	3.07	34.45
1949	2.44	1.52	1.91	2.62	3.42	2.01	4.31	5.72	3.57	2.42	2.30	2.55	34.79
1950	3.76	1.66	2.64	1.82	1.81	2.97	4.70	4.01	2.53	1.48	5.36	2.51	35.25
Av. 34 yrs.	2.42	1.88	2.54	2.96	3.44	3.95	4.43	3.40	3.79	3.26	3.31	2.18	37.56

ST. ALBANS, VT.
Record: August, 1929, to December, 1950 (broken)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1929	—	—	—	—	—	—	—	3.17	1.62	2.86	2.41	3.95	—
1930	3.47	0.59	3.93	1.74	4.80	4.64	4.67	1.50	1.86	1.98	1.75	1.15	32.08
1931	3.00	2.23	1.50	1.90	2.67	2.27	6.71	2.51	5.22	3.21	1.82	2.07	35.11
1932	2.76	1.09	3.76	3.97	2.00	2.28	5.48	2.75	1.25	6.37	3.67	1.10	36.48
1933	—	1.55	3.17	4.28	2.90	1.32	1.81	4.53	2.47	3.61	1.31	3.06	—
1934	2.49	—	1.34	3.34	0.93	4.06	3.06	1.31	4.27	2.06	2.57	—	—
1935	—	—	—	—	1.87	6.69	3.53	1.70	5.11	1.88	—	—	—
1936	—	—	—	—	4.18	—	3.74	3.06	4.99	5.06	2.68	—	—
1937	—	—	—	—	—	—	2.88	0.34	1.53	—	—	—	—
1938	—	—	1.34	—	—	—	—	—	—	—	—	—	—
1939	—	—	—	—	—	—	—	—	4.76	3.14	0.79	2.28	—
1940	0.63	1.33	3.45	2.67	3.39	3.78	2.67	1.96	3.31	2.93	3.60	3.24	32.96
1941	1.30	0.90	1.83	0.95	3.94	2.31	3.93	2.73	1.40	3.65	2.14	1.84	26.92
1942	1.33	1.52	3.42	2.92	2.78	6.47	2.85	1.55	4.75	2.69	2.29	2.68	35.25
1943	—	—	—	—	—	4.12	3.97	5.94	2.31	4.04	3.70	1.05	—
1944	2.04	2.80	1.82	2.51	1.16	1.91	4.59	2.25	5.50	2.89	2.10	1.77	30.86
1945	2.98	1.02	1.86	4.01	5.32	2.40	6.04	2.03	8.30	6.19	3.81	1.22	45.18
1946	2.35	2.09	1.27	2.88	3.51	1.57	2.96	5.65	4.33	6.52	3.67	3.41	40.21
1947	3.45	2.08	2.37	1.77	8.30	6.65	6.83	3.69	3.71	1.04	3.71	0.87	44.47
1948	0.91	1.45	2.42	3.86	3.24	3.14	3.56	2.84	1.13	2.58	6.80	3.49	35.42
1949	2.29	2.50	2.36	3.26	1.57	2.30	4.05	6.36	3.30	1.93	3.68	1.88	35.48
1950	2.86	1.68	3.14	—	1.49	2.43	2.65	8.61	3.10	2.27	4.03	4.08	—
Av. 9 yrs.	1.92	1.74	2.26	2.76	3.69	3.39	4.16	3.23	3.97	3.38	3.53	2.27	36.30

ST. JOHNSBURY, VT.—Elevation 711 feet
Record: January, 1894, to December, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1942	1.66	1.96	4.28	2.67	2.98	4.77	1.39	1.55	5.06	3.24	3.45	2.64	35.65
1943	1.12	1.79	1.96	2.33	3.97	5.64	3.56	5.10	2.41	3.85	4.72	1.01	37.46
1944	1.84	2.47	1.57	2.86	1.73	3.91	3.78	2.02	5.55	3.51	2.61	1.68	33.53
1945	3.88	2.05	1.60	4.91	6.09	5.33	5.10	1.13	7.57	4.48	3.66	2.84	48.64
1946	2.27	2.55	1.30	1.80	3.84	3.01	2.87	5.20	4.48	3.15	2.45	4.03	36.95
1947	3.51	1.95	1.94	1.84	4.73	6.88	4.58	1.38	1.14	1.03	3.56	1.34	33.88
1948	2.11	1.67	2.13	1.84	3.91	4.99	2.31	3.08	1.18	2.94	5.81	2.61	34.58
1949	2.54	2.29	1.36	2.85	3.35	2.17	3.91	2.64	3.40	2.25	2.65	2.70	32.11
1950	3.88	2.82	2.75	2.77	1.34	5.24	2.26	4.10	1.75	2.61	3.37	3.36	36.25
Av. 57 yrs.	2.31	2.04	2.48	2.58	2.99	3.52	3.73	3.59	3.59	2.88	2.92	2.43	35.06

SEARSBURG, VT. (Searsburg Mountain)—Elevation 2,400 feet
Record: November, 1924, to December, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1942	2.89	2.90	5.54	2.85	4.97	3.27	6.20	2.14	5.84	3.30	6.27	5.46	51.63
1943	2.83	2.82	2.47	3.99	10.31	3.81	4.82	6.57	1.78	5.85	7.80	1.11	54.16
1944	1.58	2.95	5.21	4.96	1.57	7.13	4.98	1.98	8.29	2.78	2.77	4.03	48.23
1945	4.16	4.31	1.77	7.74	7.42	7.12	7.72	2.40	5.59	5.08	5.95	2.57	61.83
1946	3.08	3.56	2.03	2.99	7.81	5.73	3.48	5.07	5.43	3.97	2.82	5.63	51.60
1947	5.11	2.76	5.84	4.71	6.50	5.55	6.04	7.25	2.83	1.96	5.38	2.59	56.52
1948	2.45	3.29	4.72	4.90	8.91	5.84	2.90	2.86	1.11	2.14	6.56	9.06	54.74
1949	6.01	3.26	3.02	4.33	4.38	1.77	4.81	3.77	6.44	3.32	2.79	3.10	47.00
1950	6.20	3.84	3.92	3.45	4.70	5.39	3.27	9.66	5.30	3.80	6.47	3.94	59.94
Av. 26 yrs.	3.78	3.12	4.13	4.41	4.79	4.89	5.12	4.45	4.94	4.02	5.08	3.92	52.65

SEARSBURG, VT. (Searsburg Station)—Elevation 1,530 feet
Record: November, 1923, to December, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1942	3.13	3.26	6.24	2.72	4.69	2.66	5.98	1.67	5.57	3.56	5.84	6.53	51.85
1943	3.27	2.92	3.56	4.93	9.15	3.31	4.46	4.94	1.38	6.14	6.44	0.93	51.43
1944	1.43	3.66	5.19	5.02	1.26	7.75	4.32	2.39	6.82	2.50	3.11	4.70	48.15
1945	5.04	4.86	1.90	7.72	8.53	7.57	8.19	2.13	4.53	4.71	5.12	2.63	62.93
1946	3.56	4.50	1.90	3.01	7.75	4.59	3.56	3.62	5.36	3.80	2.77	6.78	51.20
1947	5.57	3.48	7.08	5.13	6.66	5.74	7.80	6.03	1.99	1.60	5.81	3.61	60.50
1948	2.97	3.82	4.73	5.37	9.06	4.89	3.08	3.70	0.49	1.98	6.98	8.98	56.05
1949	6.27	3.64	3.35	4.94	4.58	1.80	4.55	5.25	6.42	3.00	3.17	3.45	50.42
1950	6.98	5.77	4.88	3.64	4.44	3.99	3.51	6.72	5.32	3.21	8.02	4.55	61.03
Av. 27 yrs.	4.53	3.55	4.39	4.68	4.76	4.50	4.86	4.11	4.50	3.65	5.00	4.34	52.87

SOMERSET, VT.—Elevation 2,096 feet
Record: November, 1911, to December, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1942	2.65	4.18	6.94	3.49	5.22	3.80	6.93	2.54	5.29	2.96	5.20	5.43	54.63
1943	3.53	2.93	3.88	5.12	8.02	4.26	3.06	6.28	1.52	5.54	7.06	1.19	52.39
1944	1.73	3.37	6.07	4.52	2.10	8.15	4.97	1.59	6.71	3.15	3.03	4.90	50.29
1945	5.02	6.16	2.51	7.67	7.48	6.22	8.40	1.75	4.37	4.97	7.10	3.13	64.78
1946	3.68	4.34	1.77	3.43	7.33	6.29	3.79	4.70	3.47	3.66	2.63	5.82	50.91
1947	5.21	3.44	6.34	4.12	6.05	5.23	3.81	3.45	1.50	1.63	5.85	4.32	50.95
1948	3.58	3.51	5.67	4.39	7.80	4.63	2.87	2.27	1.00	2.10	6.46	8.98	53.26
1949	6.77	3.72	3.98	4.25	4.65	1.63	4.22	3.46	5.62	2.07	2.48	4.32	47.19
1950	7.44	4.69	4.96	3.68	3.92	3.30	2.43	6.04	5.40	2.69	6.97	4.07	55.59
Av. 39 yrs.	4.46	3.80	4.58	4.52	4.51	4.52	4.57	4.07	4.39	4.07	4.88	4.31	52.68

SPRINGFIELD, VT.
Record: January, 1942, to December, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1942	2.34	1.97	4.15	2.43	—	—	—	—	3.94	2.46	4.66	4.97	—
1943	2.13	1.48	2.34	—	—	3.04	3.65	6.51	2.28	4.74	4.70	0.38	—
1944	1.28	2.57	3.55	3.47	2.26	5.57	2.62	0.76	4.65	2.87	1.60	1.84	33.04
1945	3.23	3.36	1.38	5.52	6.22	3.48	5.13	0.76	2.58	3.43	4.92	2.93	42.94
1946	2.70	2.25	0.96	2.21	6.04	1.88	4.64	3.45	4.76	2.07	1.77	3.39	36.12
1947	3.35	2.35	3.57	2.41	4.61	4.36	4.27	1.17	1.07	2.00	5.48	2.35	36.99
1948	2.70	2.87	2.42	3.26	4.53	3.63	2.98	1.67	0.54	1.90	5.65	3.29	35.44
1949	3.78	2.90	1.76	2.52	3.84	0.85	2.08	5.00	3.94	1.86	2.65	1.79	32.97
1950	4.20	3.22	3.64	2.22	2.35	2.21	2.40	5.16	3.11	1.96	5.51	2.74	38.72
Av. 7 yrs.	3.03	2.79	2.47	3.09	4.26	3.14	3.45	2.57	2.95	2.30	3.94	2.62	36.61

TOWNSHEND, VT. (Newfane)
Record: May, 1826, to September, 1833; March, 1921, to December, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1942	2.53	3.30	5.49	1.89	3.82	2.72	6.00	1.57	4.25	2.73	4.97	5.34	44.61
1943	2.71	1.53	2.51	3.93	6.70	1.77	2.20	2.90	1.08	4.69	6.92	0.61	37.55
1944	1.59	3.14	3.06	2.33	1.28	5.27	2.34	1.74	3.44	2.66	2.53	3.49	32.87
1945	3.50	4.69	1.91	6.31	8.54	7.81	5.55	1.42	4.86	2.55	4.47	2.86	54.47
1946	2.86	3.40	1.20	1.68	7.08	3.19	3.93	3.06	4.20	1.95	1.75	—	—
1947	—	—	—	—	—	—	—	—	—	—	—	—	—
1948	2.51	3.20	3.07	3.67	5.78	3.86	2.71	1.46	0.47	2.06	5.59	5.61	39.99
1949	4.31	3.28	1.91	4.06	3.13	0.79	2.64	3.64	4.66	1.81	2.66	1.62	34.51
1950	5.04	3.52	4.73	2.98	2.89	2.84	1.57	3.87	4.39	2.54	5.52	4.12	44.01
Av. 33 yrs.	3.67	3.01	3.51	3.98	3.88	3.70	4.13	3.15	4.01	3.33	4.49	3.23	44.09

TUNBRIDGE, VT.
Record: January, 1942, to December, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1942	1.68	2.24	3.70	2.67	4.03	4.62	1.82	1.23	4.88	2.64	3.49	3.47	36.47
1943	1.81	1.41	1.97	2.81	4.54	5.09	4.19	—	—	5.02	—	0.44	—
1944	1.46	2.17	—	3.47	1.13	4.80	4.17	1.16	3.82	3.75	—	—	—
1945	3.59	2.59	1.27	5.00	5.70	5.10	5.23	1.04	6.48	4.68	3.60	2.07	46.35
1946	—	—	—	—	—	—	—	—	—	—	—	3.52	—
1947	3.20	2.17	—	—	4.95	8.83	6.95	—	—	—	5.12	—	—
1948	2.72	1.72	2.73	2.51	4.78	1.82	4.26	2.47	1.08	2.66	4.88	3.27	34.90
1949	2.81	2.79	1.71	3.20	2.52	1.71	4.39	4.06	2.98	1.64	2.28	2.56	32.60
1950	3.66	1.95	3.39	1.83	1.52	2.43	2.35	3.37	2.28	2.02	4.08	2.95	31.83
Av. 5 yrs.	2.89	2.26	2.56	3.04	3.71	3.14	3.61	2.43	3.54	2.73	3.66	2.86	36.53

VERNON, VT.—Elevation 310 feet
Record: January, 1886, to December, 1901; January, 1914, to December, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1942	2.72	2.48	5.67	1.28	5.59	2.65	5.80	2.11	3.51	2.69	5.75	5.68	45.93
1943	2.22	1.67	3.03	3.68	6.20	2.06	5.49	3.97	2.15	3.92	6.56	0.45	41.40
1944	1.45	2.32	4.60	3.84	1.00	5.08	3.82	2.39	6.80	1.85	2.69	3.16	39.00
1945	3.88	4.00	1.95	5.93	7.66	7.09	6.56	1.94	3.77	2.67	3.81	3.20	52.46
1946	2.90	2.93	1.13	2.65	7.35	3.09	3.06	3.97	3.97	2.07	0.95	4.46	38.53
1947	3.71	2.38	3.11	3.79	4.71	3.64	3.13	3.93	2.98	1.55	6.09	2.29	41.31
1948	2.36	2.56	2.79	2.87	8.02	5.51	2.37	1.89	0.37	1.58	5.37	2.65	38.34
1949	3.92	3.04	1.88	3.60	2.95	1.52	2.78	—	6.97	2.08	2.50	2.80	—
1950	4.70	3.44	3.15	3.38	2.80	2.88	2.64	6.52	2.66	2.21	6.24	4.21	44.83
Av. 52 yrs.	3.40	2.86	3.38	3.37	3.47	3.66	4.01	4.03	3.82	2.98	3.80	3.22	42.00

WARDSBORO, VT.

Record: January, 1942, to December, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1942	2.55	4.12	5.65	2.61	4.46	3.57	5.99	1.55	5.12	3.02	4.59	5.82	49.05
1943	3.33	2.05	3.37	5.44	7.65	2.48	2.61	4.49	1.63	6.43	6.43	0.80	46.62
1944	1.59	3.38	5.79	3.99	2.31	7.02	2.69	1.54	5.28	2.75	3.18	4.73	44.25
1945	4.99	5.63	0.62	6.23	7.18	3.60	7.20	1.33	3.94	3.53	—	—	—
1946	—	—	—	—	—	—	—	—	—	—	—	5.35	—
1947	3.81	2.47	5.70	3.48	4.90	3.63	5.85	2.56	1.06	1.82	5.83	3.19	44.30
1948	4.00	3.98	4.00	3.95	6.01	4.24	3.33	1.99	0.39	1.91	5.25	7.60	46.65
1949	5.72	2.66	1.94	4.31	3.91	2.16	2.45	3.16	4.07	2.43	1.96	2.55	37.32
1950	6.12	4.69	5.30	3.51	3.18	2.97	1.54	5.23	4.02	2.28	6.78	4.17	49.79
Av. 7 yrs.	3.87	3.34	4.64	3.90	4.63	3.72	3.49	2.93	3.08	2.95	4.85	4.12	45.42

WATERBURY DAM, VT.

Record: August, 1941, to November, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1941	—	—	—	—	—	—	—	2.63	1.14	4.62	2.89	2.44	—
1942	1.72	2.04	3.24	3.59	2.76	5.43	1.41	2.28	4.52	4.13	3.75	3.87	38.74
1943	1.03	2.00	1.98	2.36	6.18	5.70	4.23	4.28	2.92	4.64	5.20	0.90	41.42
1944	2.25	2.45	1.48	3.54	2.35	5.08	3.56	2.63	4.98	3.90	1.11	2.21	35.54
1945	3.06	1.68	1.81	5.01	6.63	3.09	6.10	1.88	8.87	7.90	4.16	1.71	51.90
1946	1.79	2.22	1.21	2.78	5.10	2.10	3.43	5.06	—	5.84	3.79	4.17	—
1947	3.78	2.08	2.95	1.85	7.81	6.61	5.60	1.78	1.71	1.91	4.35	1.27	41.70
1948	1.62	1.49	2.33	2.97	3.97	3.17	4.09	4.73	1.63	3.27	5.02	4.43	38.72
1949	1.68	2.17	1.95	4.31	1.59	2.20	5.35	4.09	2.46	2.16	2.54	2.16	32.66
1950	2.88	2.09	3.15	1.52	1.37	3.48	2.18	5.84	2.41	3.38	3.53	—	—
Av. 7 yrs.	2.16	1.99	2.25	3.38	4.47	4.47	4.33	3.10	3.87	3.99	3.73	2.36	40.10

WEST BURKE, VT.

Record: July, 1930, to December, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1942	1.48	2.49	4.41	2.57	3.28	5.74	1.80	2.70	4.53	3.65	3.49	3.63	39.77
1943	1.12	2.04	1.95	2.40	4.23	6.55	3.93	5.58	2.92	3.85	4.39	1.48	40.44
1944	1.63	2.74	2.29	2.93	1.76	3.68	4.15	3.31	4.93	3.98	2.00	3.20	36.54
1945	4.29	2.47	1.57	4.29	5.45	3.62	4.47	1.59	9.07	5.73	4.18	2.35	49.08
1946	2.54	2.57	1.42	2.90	4.02	3.64	3.60	5.61	2.99	4.87	3.19	4.07	41.42
1947	3.63	2.53	2.46	2.00	6.45	4.05	7.88	1.42	2.36	1.11	3.31	1.63	38.83
1948	2.03	2.01	2.83	—	—	2.86	3.06	4.03	1.14	3.46	6.43	3.90	—
1949	2.95	2.72	1.92	2.67	3.34	3.61	3.58	3.18	3.52	2.66	3.59	2.94	36.68
1950	4.24	2.68	3.13	3.02	1.02	5.03	3.37	4.13	2.28	2.78	3.98	3.08	38.74
Av. 19 yrs.	2.87	2.30	2.58	3.09	3.48	3.79	4.11	3.23	4.22	3.35	3.37	2.92	39.31

WEST HARTFORD, VT.

Record: March, 1930, to December, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1942	2.04	1.93	4.19	2.55	3.12	4.59	3.65	0.72	4.80	2.75	4.43	3.76	38.53
1943	2.13	1.32	1.92	2.87	4.70	4.03	5.95	5.40	2.09	5.50	3.74	0.55	40.20
1944	1.25	2.39	2.83	2.80	3.08	6.04	3.32	1.49	6.20	3.84	1.58	2.63	37.45
1945	3.87	2.82	1.50	4.58	5.36	5.15	4.35	0.69	4.96	4.60	4.68	2.92	45.48
1946	2.69	2.42	1.11	2.30	4.29	2.27	3.19	4.93	4.30	3.14	1.48	3.75	35.87
1947	2.69	2.16	2.51	1.91	5.07	5.26	4.17	0.99	1.22	0.52	5.36	2.01	33.87
1948	2.48	2.12	2.43	2.83	4.39	3.13	4.58	2.29	0.94	2.50	4.82	2.88	35.39
1949	3.05	2.93	1.75	2.39	2.40	1.16	5.04	3.63	4.76	2.30	2.42	1.63	33.46
1950	3.85	2.71	—	2.18	1.39	2.17	2.62	3.37	2.33	2.22	4.92	2.72	—
Av. 16 yrs.	2.76	2.16	2.45	2.79	3.39	3.39	3.87	2.90	3.57	2.98	3.17	2.66	36.09

WEST TOPSHAM, VT.

Record: January, 1942, to December, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1942	1.80	2.26	4.09	3.19	4.25	4.86	2.79	1.12	5.19	3.27	3.57	3.84	40.23
1943	1.76	1.94	2.60	2.72	5.28	4.68	4.98	4.60	1.51	5.65	4.39	1.04	41.15
1944	1.67	2.55	2.66	3.46	2.39	4.34	4.09	1.17	4.64	3.65	1.97	3.01	35.60
1945	4.12	2.74	—	5.38	7.26	4.33	4.84	1.88	4.72	5.77	4.19	3.33	—
1946	2.37	3.24	1.15	2.79	4.14	2.38	3.85	6.36	3.17	4.19	2.76	4.71	41.11
1947	3.85	2.45	3.37	1.78	6.77	5.99	3.34	1.53	1.41	0.52	4.77	1.84	37.62
1948	2.65	—	2.41	2.50	5.23	2.57	2.54	3.06	0.98	2.67	5.47	3.77	—
1949	—	—	—	—	—	—	—	—	—	—	—	—	—
1950	—	—	—	—	—	—	—	—	—	2.37	3.30	3.60	—
Av. 5 yrs.	2.29	2.49	2.77	2.79	4.57	4.45	3.81	2.96	3.18	3.46	3.49	2.89	39.15

WESTON, VT.

Record: January, 1943, to December, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1943	2.84	2.18	3.02	4.03	6.03	3.22	6.22	5.53	1.73	4.00	5.37	0.78	44.97
1944	1.49	2.45	4.56	3.22	1.62	6.58	2.91	1.50	5.54	2.87	2.46	2.71	37.91
1945	3.71	4.17	1.41	5.30	6.88	4.62	5.20	1.07	4.33	5.07	5.95	2.40	50.11
1946	3.07	2.78	1.69	2.55	5.24	2.95	4.36	3.04	5.40	2.32	2.16	4.63	40.19
1947	3.95	1.97	5.83	2.63	3.93	5.83	5.67	1.84	0.84	0.72	4.66	2.21	40.08
1948	3.04	3.58	3.13	8.55	4.07	4.72	4.30	1.62	1.27	1.49	5.75	3.20	39.72
1949	3.96	—	—	—	—	—	—	—	—	—	—	2.28	—
1950	—	3.85	4.30	2.52	2.41	3.46	1.31	4.13	2.82	1.83	4.75	3.00	—
Av. 6 yrs.	3.02	2.86	3.27	3.55	4.63	4.65	4.78	2.44	3.19	2.75	4.39	2.66	42.19

WHITE RIVER JUNCTION, VT.—Elevation 400 feet

Record: January, 1914, to December, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1942	1.99	0.97	3.90	2.75	3.14	4.35	3.36	2.42	5.62	2.55	4.08	3.44	38.57
1943	2.41	1.42	1.97	3.07	4.92	4.78	4.78	6.70	1.79	4.71	5.21	0.73	42.49
1944	2.00	2.39	3.15	3.09	2.66	5.65	2.64	6.95	4.55	2.93	1.62	2.30	39.93
1945	3.98	2.51	1.59	4.87	5.48	5.49	5.68	0.74	4.79	4.11	5.48	2.95	47.67
1946	2.60	2.43	1.46	2.52	3.96	2.83	3.01	4.58	3.62	3.25	1.85	3.78	35.89
1947	3.81	2.09	2.75	1.91	5.16	5.50	4.66	1.65	0.86	0.46	4.79	2.35	35.99
1948	2.72	1.76	2.34	3.32	4.69	3.92	3.85	4.31	1.56	2.13	5.46	2.97	39.03
1949	2.71	2.58	1.88	2.52	2.54	1.38	3.65	3.10	3.44	2.14	2.16	1.77	29.87
1950	3.35	2.46	3.15	2.29	1.69	2.76	3.11	2.02	2.50	1.90	5.04	2.08	32.35
Av. 37 yrs.	2.71	2.19	2.73	3.14	2.95	3.39	3.84	3.12	3.22	2.71	3.14	2.55	35.69

WHITINGHAM, VT.—Elevation 1,500 feet

Record: October, 1922, to December, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1942	2.92	3.40	6.61	2.39	4.56	3.29	6.23	1.76	6.32	3.80	6.50	6.42	54.20
1943	3.31	2.24	3.18	4.69	8.58	3.80	4.31	6.21	1.32	6.31	6.04	0.76	50.75
1944	1.67	2.84	5.75	4.56	1.47	8.18	5.64	2.12	7.36	2.70	3.28	5.09	50.66
1945	4.76	4.47	1.67	7.91	7.90	6.33	6.23	2.95	3.34	4.04	5.32	3.06	57.98
1946	3.23	4.13	1.71	2.99	7.49	3.86	4.23	3.42	4.77	3.16	1.96	6.00	46.95
1947	4.87	2.49	5.91	4.83	6.28	5.26	8.52	3.58	1.88	1.66	6.09	3.27	54.64
1948	3.42	4.36	4.25	5.38	8.70	5.19	2.82	2.77	1.15	1.81	6.40	8.73	54.98
1949	7.69	3.56	2.92	4.63	4.46	1.67	3.74	4.41	5.98	2.61	2.45	3.45	47.57
1950	7.23	5.57	4.50	3.25	4.76	4.76	3.98	5.59	5.15	3.06	7.84	4.72	60.41
Av. 28 yrs.	4.26	3.34	3.97	4.48	4.31	4.27	4.45	3.75	4.33	3.42	4.50	4.16	49.24

WILDER, VT.—Elevation 400 feet
Record: May, 1920, to December, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1942	1.65	1.40	3.63	2.52	3.18	3.75	3.05	0.91	4.27	2.35	4.79	2.72	34.22
1943	2.03	1.13	1.67	2.65	4.93	4.22	4.70	7.14	1.70	4.73	4.99	0.61	40.50
1944	1.60	2.24	2.83	3.01	2.79	5.37	2.27	1.02	4.41	2.92	1.49	1.89	31.84
1945	3.87	2.39	1.70	5.26	5.33	4.75	6.15	0.69	4.53	4.23	5.62	2.81	47.33
1946	2.30	2.13	1.26	2.24	3.58	2.32	2.97	4.27	3.49	3.34	1.51	3.50	32.91
1947	3.41	1.86	2.30	1.69	5.14	4.70	4.25	2.01	0.82	0.42	4.74	2.22	33.56
1948	2.78	1.77	2.23	3.02	4.65	3.08	4.20	4.42	1.46	2.28	5.27	2.69	37.85
1949	2.72	2.45	1.64	2.26	2.36	2.57	3.99	2.70	3.73	2.20	2.32	2.08	31.02
1950	3.31	2.53	2.62	2.06	1.52	2.71	3.54	1.91	2.50	1.69	—	1.95	—
Av. 29 yrs.	2.43	1.87	2.34	2.99	2.97	3.22	4.12	2.98	3.26	2.74	3.29	2.27	34.48

WILMINGTON, VT.
Record: May, 1930, to December, 1945

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1942	2.70	3.72	5.79	2.87	4.52	2.81	5.58	1.72	4.71	3.02	5.04	5.66	48.14
1943	3.16	2.56	3.55	4.06	7.93	3.43	4.20	4.76	1.76	5.04	5.64	0.56	46.65
1944	1.74	3.91	5.31	4.53	1.35	6.12	4.10	1.57	4.59	2.43	3.31	3.88	42.84
1945	4.74	5.33	1.66	6.48	6.62	7.48	6.46	1.63	3.98	3.77	4.25	3.82	56.22
Av. 15 yrs.	4.09	3.37	4.29	4.62	3.98	4.43	5.03	3.46	4.77	3.67	4.25	3.82	49.78

WOODSTOCK, VT.—Elevation 700 feet
Record: January, 1857 (except 1868 and 1869), to December, 1950

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1942	2.79	2.14	4.53	3.10	3.81	3.81	3.21	1.38	4.10	2.62	4.62	4.52	40.63
1943	2.52	1.66	2.00	3.58	6.14	3.95	4.12	5.04	2.39	5.93	4.86	0.62	42.81
1944	2.04	2.60	3.18	3.03	1.96	6.34	2.56	0.94	5.51	2.98	3.12	1.94	36.20
1945	4.08	2.50	2.07	3.79	6.21	4.99	6.09	0.96	4.61	4.76	6.04	3.25	49.35
1946	2.49	2.75	1.26	2.74	4.33	3.07	3.38	5.02	4.85	2.62	2.01	5.57	40.09
1947	4.24	2.66	3.87	2.59	5.34	8.14	5.73	1.69	1.28	0.43	6.19	2.64	44.80
1948	3.55	1.97	2.66	4.10	5.45	2.92	4.53	3.50	0.76	2.89	6.01	4.86	43.20
1949	2.87	—	2.10	3.60	2.60	3.67	4.01	3.69	4.08	2.61	3.13	1.04	—
1950	5.25	3.76	4.23	1.51	1.99	3.09	3.52	2.93	1.74	2.44	5.11	3.81	39.38
Av. 82 yrs.	3.06	2.71	3.15	2.96	3.39	3.56	4.02	3.26	3.42	3.05	3.40	2.94	38.92

PROCEEDINGS

FEBRUARY 1956 MEETING

HOTEL STATLER, BOSTON, MASS.

THURSDAY, FEBRUARY 16, 1956

President Allan F. McAlary in the Chair.

Secretary Knox announced the election of the following to membership in the Association:

Thomas E. Duff, Municipal Manager, Town and Village, Middlebury, Vt.; William E. Godfrey, Consulting Engineer, James F. MacLaren Associates, St. John, New Brunswick, Canada; James J. McCarthy, Sales Representative, U. S. Pipe & Foundry Co., Boston, Mass.; John P. Sullivan, Foreman, Department of Water Supply, New York, N. Y.; Wilfred H. Goodridge, Superintendent, Water Department, Westminster, Mass.; Joan Goostray, Coffin & Richardson, Inc., Boston, Mass.; Willard L. Gage, Water and Sewer Department, Bridgewater, Mass.

Associates:

Connecticut Chlorine Products, Inc., Waterbury, Conn.; New England Pump and Machinery Co., Quincy, Mass.; Mogan-Walker Co., Contractors, Norwood, Mass.

PRESIDENT MCALARY. You have all seen by the notice that we are proposing to take action this afternoon upon a proposed amendment to our constitution, relating to the dues of the Association. This is the first increase in dues since 1919, 36 years ago, when the dues were raised from $4 to $6. For those who do not have the cards in hand I shall read what the proposed increase is: For Members, from $6.00 a year to $8.00 a year—an increase of $2.00; Honorary Members, no dues; Juniors, $3.00, with no change; Associates, from $20.00 to $25.00 a year; and Corporates, from $10.00 to $15.00 a year.

I do not need to tell you that the expenses of the Association have been increasing, especially in the last few years, and we have been operating on a deficit for the last seven years. This operation on a deficit has reduced our invested funds from about $24,000 to $17,000, and $17,000 is almost the total annual budget.

This increase has been recommended by our Finance Committee, and it has been approved by the Executive Board. It is felt that it will yield sufficient revenue to meet our anticipated annual expenses.

The matter is now before the meeting, on the adoption of this amendment to our constitution.

Upon motion of E. Sherman Chase, duly seconded, it was VOTED to adopt this amendment to the constitution.

A paper on "Non-destructive Testing of Water Works Equipment" was read by Robert J. Halliday, Vice-President, Arnold Greene & Co., Inc., Cambridge, Mass.

A paper on "The Case for a Positive Well-Field Maintenance Program" was read by E. Boyd Livesay, Superintendent, Brunswick and Topsham Water District, Brunswick, Me.

MARCH 1956 MEETING

HOTEL STATLER, BOSTON, MASS.

THURSDAY, MARCH 15, 1956

President Allan F. McAlary in the Chair.

The President announced the deaths of Past President and Honorary Member Harry U. Fuller and Past President Arthur C. King.

Secretary Knox announced the election of the following to membership in the Association:

Cecil A. Bissonnette, Village Manager, Bellows Falls, Vt.; Walter F. Burdick, Director, Public Works Department, Natick, Mass.; Kenneth R. Couch, Superintendent, Water Department, North Bennington, Vt.; Lester M. Klashman, Assistant Regional Engineer, U. S. Public Health Service, New York, N. Y.; Baxter Robertson, Engineer, Aetna Engineering Co., Boston, Mass.; E. Locke Robinson, Water Commissioner, Windsor, Vt.; Robert H. Varney, Assistant Manager, Camden & Rockland Water Co., Rockland, Me.; Walter A. Ware, Assistant Manager, Milford Water Co., Milford, Mass.; John E. Bamber, Superintendent of Public Works, Canton, Mass.

Associate Member:

Warren Steam Pump Co., Inc., Warren, Mass.

Upon motion of Roger W. Esty, duly seconded, it was VOTED that the following five Past Presidents be named as members of the Nominating Committee: Stanley F. Dore, Frederick O. A. Almquist, Thomas R. Camp, Sidney S. Anthony, and Donald C. Calderwood, with Mr. Camp as Chairman.

PRESIDENT MCALARY. At the 1955 Annual Convention at Lake Placid, the Association voted that the Temporary Scholarship Committee submit its report to the Association at this meeting. I shall call on Chairman William Duffy of the Temporary Scholarship Committee.

William B. Duffy. President McAlary and members. First I should like to thank the members of the Scholarship Committee who worked so long and hard on this problem. Secondly, I should like to thank those members who have contributed their opinions and their help to the Committee. I should also like to thank those members who have voluntarily said that they would contribute toward the fund if the Association establishes this scholarship.

Now, with your permission, I shall go ahead and read the report to you:

"To the New England Water Works Association:

"The report of the Scholarship Committee, appointed by Past President Roger G. Oakman, made to the Association at the Lake Placid Club Convention was returned to the Committee for further study and report not later than the March, 1956, meeting.

"Your Committee now recommends that an Association-sponsored scholarship, to be known as the New England Water Works Association Scholarship, be established to encourage and assist deserving and capable individuals to enter the water-works field and to progress therein by means of scholarship grants or loans made available in the following manner.

"(1) A permanent Scholarship Committee of seven members, including the Treasurer of the New England Water Works Association, be appointed before November 1 by the President and the Executive Committee, to solicit and accept donations and to administer the scholarship fund for the advancement of water-works practice through the members of the New England Water Works Association. Two members of the Scholarship Committee to be appointed for one year, two for two years and two for three years initially, and two members for three years thereafter. The Treasurer of the Association will be a member of the Committee *ex officio*. The Committee shall elect its own Chairman, Vice-Chairman and Secretary. The Committee shall report annually at the Annual Convention of the Association.

"(2) Members, associate members, corporate members or individuals, companies or associations be approached by the Scholarship Committee for contributions to a scholarship fund of Twenty-five Thousand Dollars or more. Income may be expended or loaned for scholarships when contributions amount to Ten Thousand Dollars. At no time shall disbursements from the Fund reduce the Fund to an amount less than the sum of the actual contributions.

"An initial contribution of One Thousand Dollars from invested funds is to be made by the New England Water Works Association and additional sums may be added by the Association at any time.

"The Scholarship Fund is to be deposited in such savings bank or other bank or invested in government or other bonds by the Treasurer as the Scholarship Committee directs or approves. Disbursements from the Fund are to be made by the Treasurer as directed and approved by the Scholarship Committee.

"(3) Scholarships be awarded by the Scholarship Committee on the basis of merit, character, and need to members and junior members of the New England Water Works Association with preference given to applicants whose programs are considered by the Scholarship Committee as beneficial to waterworks practice in New England. Loans may be made by the Scholarship Committee from the Scholarship Fund upon such terms and conditions as the Committee may decide.

"(4) The Association is to provide annually sufficient funds for the Scholarship Committee for promoting and administering the Scholarship Fund. The Scholarship Committee is to have full authority to make such rules and regulations for the selection of candidates and the award of scholarship loans and grants as are not inconsistent with the general policy herein stated.

"(5) The Committee recommends that the program outlined herein be submitted to the members of the Association for letter ballot with the results to be reported at the May meeting of the Association. If a majority of the ballots cast are in favor the program shall become effective.

"Respectfully submitted,

"THOMAS R. CAMP
KENNETH F. KNOWLTON
THOMAS S. LAWRENCE
ROGER W. ESTY
WILLIAM B. DUFFY, *Chairman.*"

PRESIDENT MCALARY. You have heard the reading of the report of the Temporary Scholarship Committee. The question before you is upon the acceptance of this report, but note that the last paragraph calls for submitting the question to the members by mail, and therefore the Chair feels that the acceptance of the report automatically sends it to the membership. The question is before you now.

A MEMBER. I hereby move that the report be accepted.

VOICES. I second the motion.

PRESIDENT MCALARY. Is there any discussion? The Chair hears none. Those in favor of accepting this report, contingent upon the favorable action by the membership, will please say "Aye." Those opposed will say "No." The Ayes have it and it is a vote.

The technical session consisted of a panel discussion on Emergency Water Supply, Fire Fighting and Civil Defense. The moderator for this discussion was Percy C. Charnock, Manager, New England Fire Insurance Rating Association, Boston, Mass.

A paper, "Water for War-Time Protection," prepared by Horatio Bond, Chief Engineer, National Fire Protection Association, Boston, Mass., was read by Mr. Charnock.

A paper on "Elements of an Emergency Water System for Fire Service" was read by John C. Adams, Jr., Hydraulic Engineer, Coffin & Richardson, Inc., Boston, Mass.

A paper on "Civil Defense in Massachusetts" was read by Brigadier General John J. Maginnis, Director, Massachusetts Civil Defense Agency, Natick, Mass.

A paper on "Water Supply, Fire Fighting, and Civil Defense" was read by Frank McNea, Chief, Fire Office, Federal Civil Defense Administration, Battle Creek, Mich.

The discussion of these papers was entered into by Frank Soracco of the Federal Civil Defense Administration, Roger W. Esty, Albert S. Genaske, and Thomas F. Gorman, Chief of Fire Department, Quincy, Mass.

INDEX OF ADVERTISERS

	Page
Badger Meter Mfg. Co.	Following front cover
Bahr, Ray	xviii
B-I-F Industries, Inc.	Following front cover
Bingham & Taylor Corp.	Following front cover
Brown Co.	xviii
Caldwell Co., George A.	iv
Camp, Dresser & McKee	ii
Cast Iron Pipe Research Assn.	xxv
Cement Lined Pipe Co.	xviii
Centriline Corp.	Following front cover
Chapman Co., R. E.	ii
Coffin and Richardson	ii
Crosby, Irving B.	ii
Eddy Valve Co.	xii
Eureka Pipe Co., Inc.	xiv
Fairbanks, Morse & Co.	Following front cover
Fay, Spofford & Thorndike	ii
Flexible Sales Corporation	xviii
Ford Meter Box Co., The	Following front cover
Gunite Restoration Co., Inc.	ii
Haley & Ward	ii
Hays Mfg. Co.	xiii
Hazen & Sawyer	iii
Hersey Mfg. Co.	ix
Hilco Supply, Inc.	xix
Hydraulic Development Corp.	vii
Johns Manville Sales Corp.	viii
Keasbey & Mattison Co.	v
Kennedy Valve Mfg. Co.	xv
Knowles, Inc., Morris	ii
Layne-New York Co.	iii
Leadite Co.	Back cover
Leggette, Brashears & Graham	ii
Lock Joint Pipe Co.	Following front cover
Ludlow Valve Mfg. Co.	Following front cover
Maguire & Assoc., Chas. A.	iii
Maher Co., D. L.	iii
Metcalf & Eddy	ii
Mills Engineering Co., Inc.	xiv
Morris Knowles, Inc.	ii
Mueller Co.	Following front cover
National Water Main Cleaning Co.	x
Neptune Meter Co.	Following front cover
Pierce-Perry Co.	iii
Pipe Founders Sales Corp.	xiv
Pirnie, Malcolm	iii
Pitometer Assoc., Inc., The	iii
Pittsburgh-Des Moines Steel Co.	Following front cover
Pittsburgh Equitable Meter Div.	Following front cover
Pollard Co., Inc., Joseph G.	Following front cover
Prescott & Sons, Inc., H. R.	xvi
Public Works Supply Co.	xviii
Rensselaer Valve Co.	Following front cover
Rockwell Manufacturing Co.	Following front cover
Ross Valve Mfg. Co.	xvii
Smith Mfg. Co., The A. P.	Following front cover
Torrington Supply Co., Inc.	xx
Turbine Equipment Co. of New England	Following front cover
U. S. Cast Iron Pipe & Foundry Co.	xxvi
Utilities Supply Corp.	xx
Wallace & Tiernan Co., Inc.	xi
Weston & Sampson	iii
White Construction Co., R. H.	xiv
Whitman & Howard	iii
Wood Co., R. D.	Following front cover
Worthington-Gamon Meter Div.	vi

(Classified index on page xxiii)

ENGINEERS

Coffin & Richardson, Inc.

Consulting Engineers

Water Supply, Sewerage, Flood Control
Investigation, Design, Valuation
Incinerators

68 Devonshire St. . . . . Boston, Mass.

HALEY & WARD
ENGINEERS

Successors to Frank A. Barbour

Water Works and Sewerage
Valuations
Supervision of Construction and Operation

TREMONT BUILDING BOSTON, MASS.

MALden 2-3800

Gunite Restoration Co., Inc.

Specializing in Pressure Concrete and Grouting

595 Broadway, Malden 48, Mass.

R. E. CHAPMAN COMPANY
Oakdale, Massachusetts

GRAVEL DEVELOPED AND
GRAVEL PACKED WELLS

All Sizes to 60" Diameter
Best Equipped for Complete Test Drilling and Development of Large Supplies

Tel. WEST BOYLSTON 5-3727
5-3221

CAMP, DRESSER & McKEE

Consulting Engineers

6 Beacon Street
Boston 8, Massachusetts

Water Works and Water Treatment; Sewerage and Sewage Treatment; Municipal and Industrial Wastes; Investigations and Reports; Design and Supervision; Research and Development; Flood Control.

Fay, Spofford & Thorndike, Inc.
ENGINEERS

Water Supply - Sewerage - Drainage
Structural and Foundation Problems

Investigations Reports Valuations
Designs Engineering Supervision

11 BEACON STREET BOSTON

MORRIS KNOWLES INC.

Engineers

Water Supply and Purification, Sewerage and Sewage Disposal, Industrial Wastes, Valuations, Laboratory, City Planning.

1312 PARK BUILDING
PITTSBURGH 22, PA.

METCALF & EDDY
ENGINEERS

Water, Sewage, Drainage, Refuse and Industrial Wastes Problems

Airports Valuations

Statler Building
Boston 16

IRVING B. CROSBY

Consulting Engineering Geologist

Investigations and Reports
Dams, Reservoirs, Tunnels, Ground Water Resources and Supplies

6 Beacon Street, Boston 8, Mass.

Leggette, Brashears & Graham

Consulting Ground Water Geologists

Water Supply Salt Water Problems
Dewatering Investigations
Recharging Reports

551 Fifth Avenue New York 17, N. Y.

ENGINEERS

Malcolm Pirnie Engineers

Civil and Sanitary Engineers

Malcolm Pirnie Ernest W. Whitlock
Robert D. Mitchell Carl A. Arenander
Malcolm Pirnie, Jr.

Investigations, Reports, Plans
Supervision of Construction
and Operations
Appraisals and Rates

25 West 43rd St. New York 36, N. Y.

THE PITOMETER ASSOCIATES, INC.
ENGINEERS

Water Waste Surveys
Trunk Main Surveys
Water Distribution Studies
Water Measurements & Special
Hydraulic Investigations

50 Church Street New York City

Charles A. Maguire & Associates

Engineers

14 Court Square Boston 8, Mass.

Hazen and Sawyer
ENGINEERS

Richard Hazen Alfred W. Sawyer

Municipal and Industrial Water Supply
Purification and Distribution
Sewage Works and Waste Disposal
Investigations, Design,
Supervision of Construction and Operation

110 East 42nd St. New York 17, N. Y.

D. L. MAHER CO.

Water Supply Contractors

Gravel Wall and Driven Wells
Municipal and Industrial Supplies

38B Brattle Street - KIrkland 7-1438
Cambridge, Massachusetts

WESTON & SAMPSON

Consulting Engineers

Water Supply and Sewerage
Chemical and Bacteriological
Laboratory

14 BEACON ST. BOSTON, MASS.

WHITMAN & HOWARD

Engineers

Established 1869

Investigations, Designs, Estimates, Reports and Supervision, Valuations, etc., in all Water Works and Sewerage Problems.

89 BROAD ST. BOSTON, MASS.

PIERCE-PERRY CO.

Wholesalers of

Water Works Brass Goods
Byers Wrought Iron Pipe
Youngstown Steel Pipe
Valve and Service Boxes

236 Congress St., Boston, Mass.
Telephone, HAncock 6-7817 — 6-7818

LAYNE - NEW YORK CO. Inc.

SUCCESSORS TO

Layne-Bowler New England Corp.

Well Water Supply Contractors

New England Headquarters
15 Ryder Street, Arlington, Mass.

GEORGE A. **CALDWELL** COMPANY

CALDWELL adopted a slogan in 1936 for what we had been selling since becoming established in 1921. This is the slogan . . . .

"Everything for Water Service Work from Main to Meter"

And since 1921 we have steadily improved the qualities of our lines and our services to you. . . .

Our business continues to grow because of this service, which has brought to us many new friends and customers besides those who have been with us since 1921.

It is a pleasure to meet you and put our story before you again through the pages of this journal.

GEORGE A. CALDWELL CO.

592 East First Street **South Boston 27, Massachusetts**

Phones ANdrew 8-1172 — 8-1173

The Heffernan Press

150 Fremont Street

WORCESTER, MASSACHUSETTS

Printers to
THE JOURNAL OF THE NEW ENGLAND WATER WORKS ASSOCIATION
and *other* good publications.

NEW!

"FLUID-TITE"® COUPLING*

For "Century®" Asbestos-Cement Pressure Pipe

SELF-ENERGIZING SEALING RINGS allow pipe to slide into coupling easily. Water pressure automatically expands the rings. The higher the internal water pressure, the tighter the seal.

- **Cuts installation time**
- **Provides permanent, water-tight seal**

Now, using the new "Fluid-Tite" Coupling, crews can lay more "Century" Asbestos-Cement Pressure Pipe per hour than ever before. No cumbersome coupling pullers are needed. "Century" Pipe can be easily connected with standard valves, hydrants and fittings.

Thanks to the speed and simplicity of using "Fluid-Tite" Couplings, there is no need to hold up pipe-laying operations in rain, snow or wet trench conditions. Specify "Fluid-Tite" Couplings with "Century" Asbestos-Cement Pressure Pipe. You'll get more rapid installation, plus full flow and low maintenance. Write today for details.

"Century" Pipe and "Fluid-Tite" Couplings meet A.W.W.A., A.S.T.M., and Federal specifications and are approved by Underwriters' Laboratories, Inc.

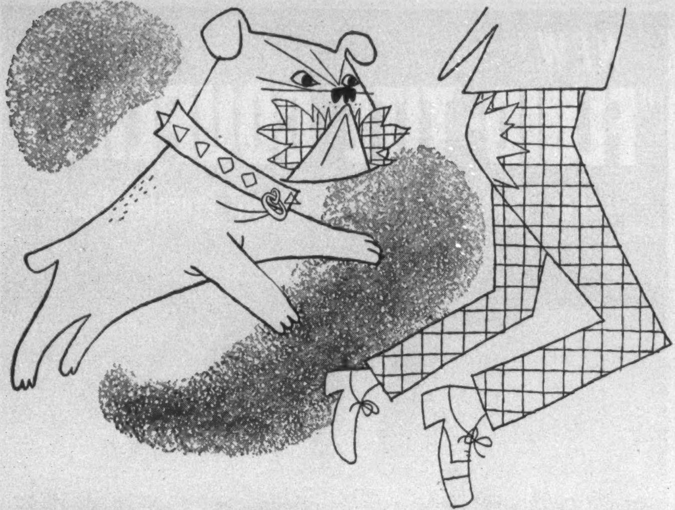
New self-energizing "Fluid-Tite" sealing rings have tapered surfaces, and compress, to permit pipe to slide in easily.

When main is filled, rings expand with application of internal water pressure, creating a tighter seal.

KEASBEY & MATTISON
COMPANY • AMBLER • PENNSYLVANIA

K&M best in asbestos ®

*PATENT APPLIED FOR



WATCH DOG

ON GUARD 24 HOURS A DAY

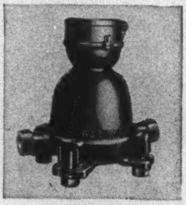
Profits in water service today are measured in pennies. Worthington-Gamon WATCH DOG Water Meters guard your profits three vital ways:

Accuracy . . . provides precise measurement of water.

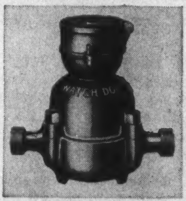
Simplicity . . . of design makes for ease of repair.

Durability . . when you invest in WATCH DOG Meters, you are assured of long life equipment.

The majority of large U.S. cities are using WATCH DOG Meters. Write today for detailed information, concerning your specific requirements. Representatives and offices in all principal cities.



FROST PROOF



SPLIT CASE

WORTHINGTON-GAMON METER DIVISION

WORTHINGTON CORPORATION

296 SOUTH STREET, NEWARK 5, NEW JERSEY

"The sign of value around the world"

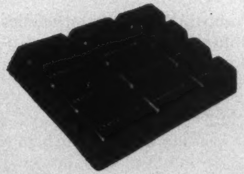
YOU WERE DOING THIS

WHEN THE FIRST HYDRO-TITE JOINTS
WERE BEING POURED -

HYDRO-TITE

(POWDER)

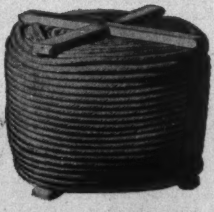
For over 40 years HYDRO-TITE has been faithfully serving water works men everywhere. Self-caulking, self-sealing, easy-to-use. Costs about 1/5 as much as lead joints. Packed in 100 lb. moisture-proof bags.



HYDRO-TITE

(LITTLEPIGS)

The same dependable compound in solid form — packed in 50 lb. cartons — 2 litters of pigs to the box — 24 easy-to-handle Littlepigs. Easier to ship, handle and store.



FIBREX

(REELS)

The sanitary, bacteria-free joint packing. Easier to use than jute and costs about half as much. Insures sterile mains and tight joints.

HYDRO-TITE

HYDRAULIC DEVELOPMENT CORPORATION

Main Sales Office 50 Church Street New York [illegible] W. Medford Station Boston, M[illegible]

GOING IN . . .
. . . a long-term investment

An asbestos-cement product

It's Transite Ring-Tite Pressure Pipe

● Transite® Ring-Tite® Pressure Pipe is a community investment that pays off year after year!

Its remarkably high flow characteristics protect that investment by keeping maintenance and pumping costs at a minimum during its long service life.

Corrosion resistant

Transite Pipe is strong, durable, and highly resistant to corrosion. And it is immune to tuberculation, the form of interior corrosion that chokes the flow and increases pumping costs. Transite cannot tuberculate, thus its original high flow capacity is maintained, and pumping costs are kept at a minimum, year after year.

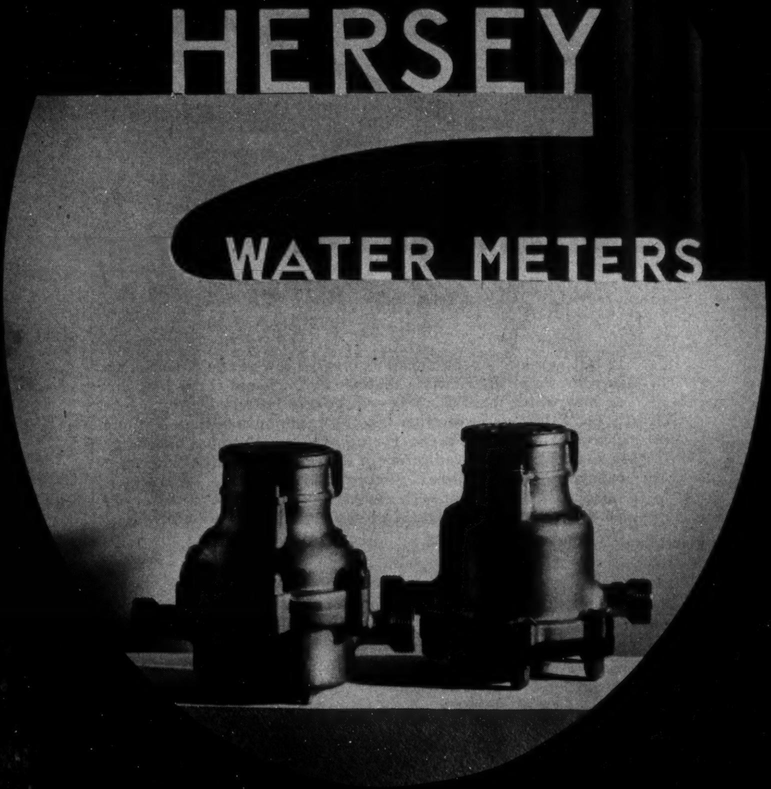
The Ring-Tite Coupling, with rubber rings compressed and locked in place, forms a joint that is tight yet flexible. Rings cannot blow out, and the automatic separation of the pipes within the coupling helps to relieve line stresses.

For further information about Transite Pressure Pipe and the Ring-Tite Coupling, write for Booklet TR-160A. Address Johns-Manville, Box 60, New York 16, N. Y. In Canada, Port Credit, Ontario.

JOHNS-MANVILLE JM PRODUCTS

Johns-Manville TRANSITE PRESSURE PIPE

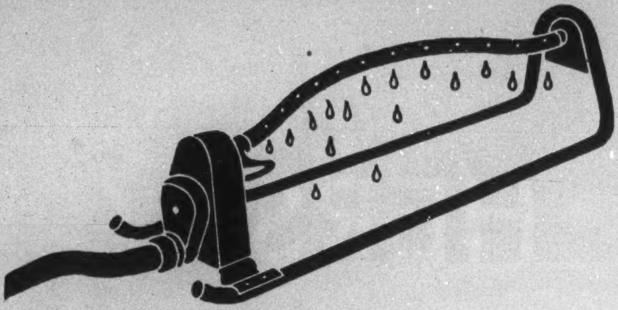
WITH THE RING-TITE COUPLING


HERSEY
WATER METERS

HERSEY MANUFACTURING COMPANY

SOUTH BOSTON, MASS.

BRANCH OFFICES: NEW YORK — PORTLAND, ORE. — PHILADELPHIA — ATLANTA — DALLAS — CHICAGO
SAN FRANCISCO — LOS ANGELES



a summer problem
will be no problem
if you call in National now!

If last summer's peak demands created low pressure problems in your water distribution system call National for a *free survey* on how water main cleaning will uprate your system.

You'll find as have other leading communities that National cleaning is an investment—not an expense. National cleaning is so effective that *restoration of at least 95%* of the original capacity of your mains is guaranteed!

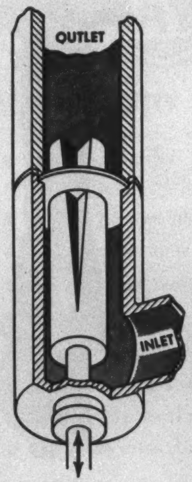
Charges are modest with little if any interruption to service. So, for compliments instead of complaints why not call National right now?

Call in National today!

NATIONAL WATER MAIN CLEANING COMPANY
50 Church Street • New York, N. Y.

ATLANTA, GA., 333 Candler Building • BERKELEY, CALIF., 905 Grayson Street • DECATUR, GA., P. O. Box 385 • BOSTON, MASS., 115 Peterboro Street • CHICAGO, 122 So. Michigan Avenue • ERIE, PA., 439 E. 6th Street • FLANDREAU, S.D., 315 N. Crescent Street • KANSAS CITY, MO., 406 Merchandise Mart and 2201 Grand Avenue • LITTLE FALLS, N.J., Box 91 • LOS ANGELES, 5075 Santa Fe Avenue • MINNEAPOLIS, MINN., 200 Lumber Exchange Building • RICHMOND, VA., 210 E. Franklin Street • SALT LAKE CITY, 149-151 W. Second South Street • SIGNAL MOUNTAIN, TENNESSEE, 204 Slayton Street • MONTREAL, CANADA, 2032 Union Avenue • WINNIPEG, CANADA, 576 Wall Street • HAVANA, CUBA, Lawrence H. Daniels, P. O. Box 531 • SAN JUAN, PUERTO RICO, Luis F. Caratini, Apartado 2184.

THE WALLACE & TIERNAN
V-NOTCH
variable-orifice
. . . a new concept for chlorinator control



The W&T V-notch Variable-Orifice is the heart of a new chlorinator control system. With the system, a constant differential vacuum is maintained across the V-notch Variable-Orifice and the flow of chlorine gas is adjusted by varying the area of the orifice.

The W&T V-notch Variable-Orifice has these features:

- Wide range adjustment of chlorine flow
- Excellent reproducibility of flow by a simple adjustment
- Same % accuracy over entire wide flow range

As can be seen in the diagram, the V-notch Variable-Orifice is formed by a cylindrical plug positioned inside a matched, circular ring. A V-shaped groove is machined along the length of the plug. The groove starts near one end of the plug and gradually enlarges to its maximum width and depth at the other end of the plug. The V-notch Orifice is formed at the intersection of the grooved plug and the matched ring. The orifice area is varied simply and positively by positioning the plug backward or forward inside the fixed ring.

The V-notch Variable-Orifice is just one design feature of the new W&T V-notch line of Chlorinators. Get all the facts about the W&T V-notch chlorinators before you buy chlorination equipment.

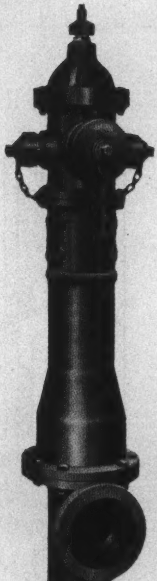
WALLACE & TIERNAN INCORPORATED
25 MAIN STREET, BELLEVILLE 9, NEW JERSEY

S-108

For YEARS and YEARS and YEARS YOU CAN DEPEND UPON

EDDY

EDDY VALVE CO.
WATERFORD, N.Y.



EDDY can supply replacement parts for any Eddy Valve or Hydrant ever installed! This is important to you because the Valves and Hydrants you buy today must serve several generations yet unborn. You want no "orphans" in your system. Eddy Hydrants and Eddy Valves are backed by Eddy Valve Company's 104 years of dependable operation — your assurance that replacement parts will be available during the years to come.

• • •

H. R. Prescott & Sons, Inc.
NEW ENGLAND SALES AGENTS
Box 7 · Greendale Sta.
Worcester 6, Massachusetts
Tel. West Boylston TE 5-4431

EDDY VALVE COMPANY

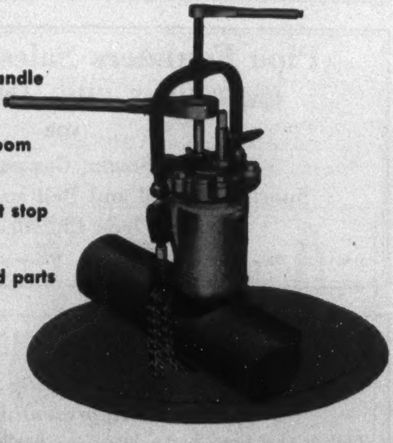
WATERFORD, NEW YORK

WANT THE BEST?

HAYS MODEL B

Aluminum Alloy Tapping Machine

- Designed for the man in the ditch
- A third less weight to handle
- Requires less time
- Requires less working room
- Easier to operate
- No disassembly to insert stop
- Positive grip on main
- Renewable bearings and parts
- Complete with chest



Your HAYS distributor or our representative will be glad to demonstrate the Model B . . . or write to us about one for a trial on the job by your own men.

Join the A. W. W. A. HAYS is one of the eleven Charter Members of the Manufacturers Section of the American Water Works Association.

HAYS®

WATER WORKS PRODUCTS
HAYS MANUFACTURING CO.
ERIE, PA.

FLANGED PIPE AND SPECIALS
CURB AND GATE BOXES
CRESCENT DIAPHRAGM PUMPS
WATER WORKS BRASS GOODS
HYDRANTS AND VALVES
PIPELINE EQUIPMENT AND TOOLS
WROUGHT IRON AND STEEL CEMENT LINED PIPE
LEAD LINED FITTINGS

EUREKA CEMENT LINED PIPE CO., INC.

Telephone: LY-3-9550
591-593 WASHINGTON STREET LYNN, MASSACHUSETTS

R. H. WHITE CONSTRUCTION CO., Inc.

GENERAL CONTRACTORS

Water Mains
Pumping Machinery
Pumping Stations
Standpipe Foundations
Sewerage Disposal

41 CENTRAL ST., AUBURN, MASSACHUSETTS
(Tel. Auburn 8121)

Pipe Founders Sales Corporation

CAST IRON PIPE AND FITTINGS
FOR
Water, Steam, Gas and Culverts
Special Flanged and Bell and Spigot Castings
Lyncast Iron Chemical Castings

Office: 131 State Street, Boston 9 Warehouse and Yard: East Cambridge, Mass.

MILLS ENGINEERING CO., INC.

10 High Street, Boston, Massachusetts

Representing

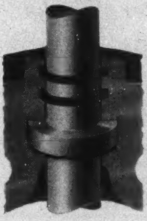
Philadelphia Gear Works, Inc.
Gears, Speed Reducers
Limitorque Valve Controls
American Well Works
Sewage and Water Process Equipment
Pumps

Bradley Washfountain Co.
Group Washing Equipment

Blackburn-Smith Mfg. Co., Inc.
Pneumatic Ejectors
Filters
Strainers

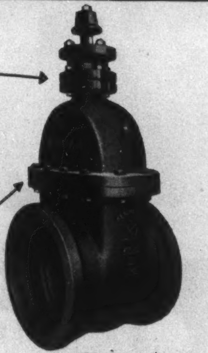
KENNEDY A.W.W.A. Gate Valves

Give You More Value For Your Valve Dollar . . .



O-RING SEALS

Provide excellent seal, prevent binding of stem and result in very easy valve operation. KENNEDY O-Rings are located above collar, permit repacking under pressure. Optional on KENNEDY non-rising stem A.W.W.A. valves.



KENNEDY Fig. 56
A.W.W.A. Standard Iron-Body Double-Disc Gate Valve, with Bell Ends.

STRONGER CONSTRUCTION

Rugged design and construction features iron that is 50% stronger than ordinary cast iron to keep KENNEDY Valves doing a better job over a longer, more dependable operating life.

KENNEDY manufactures a complete line of water works valves. Sizes range from 2" to 48" including non-rising stem and outside-screw-and-yoke valves. These valves feature the hook-and-wedge type disc mechanism for easier, better and more positive valve operation. A wide variety of pipe connections are available.

For maximum service life, for the greatest value for your valve dollar, specify KENNEDY valves and fire hydrants. Remember, KENNEDY means dependability in valves, fire hydrants and accessories.

Fig. 571

Fig. 561

Fig. 566

Fig. 566G

Fig. 566FTR

Write today for NEW A.W.W.A. Valve Bulletin

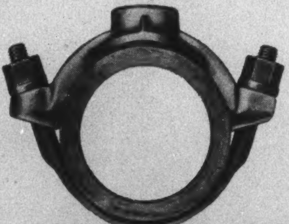
THE KENNEDY VALVE *MFG. CO. • ELMIRA, N. Y.*

VALVES • PIPE FITTINGS • FIRE HYDRANTS

OFFICE AND WAREHOUSES IN NEW YORK CHICAGO SAN FRANCISCO ATLANTA SALES REPRESENTATIVES IN PRINCIPAL CITIES

CALL PRESCOTT

When You Need Saddles or Other



Quality Water Works

Supplies

SMITH-BLAIR

CLOW-DRESSER

SKINNER

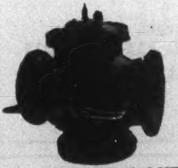
H. R. PRESCOTT & SONS, INC.

QUALITY WATER WORKS SUPPLIES SINCE 1914

BOX 7 — GREENDALE BRANCH — WORCESTER 6, MASS.
TELEPHONE WEST BOYLSTON 5-4431

1879—ROSS—1879

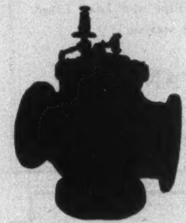
AUTOMATIC VALVES



Controls elevation
of water
in
tanks, basins
and
reservoirs

ALTITUDE VALVE

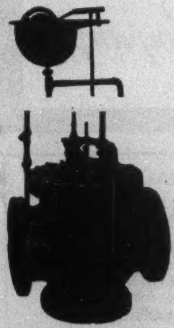
1. Single Acting
2. Double Acting



Maintains
desired discharge
pressure
regardless
of change
in
rate of flow

REDUCING VALVE

Regulates pressures in gravity and pump systems; between reservoirs and zones of different pressures, etc.



Maintains
levels in tank,
reservoir
or basin

1. As direct acting

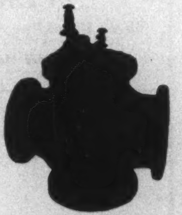
2. Pilot operated and with float traveling between two stops, for upper and lower limit of water elevation.

FLOAT VALVE

A self contained
unit, with
controls
three or more
automatic

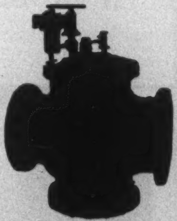
COMBINATION VALVE

Combination automatic control both directions through the valve.



Maintains
safe operating
pressures
for
conduits,
distribution and
pump
discharge

SURGE-RELIEF VALVE



Electric
remote control—
solenoid or
motor
can be
furnished

REMOTE CONTROL VALVE

Adapted for use as primary or secondary control on any of the hydraulically controlled or operated valves.

ROSS VALVE MFG. CO., INC. Box 592 TROY, N. Y.

PUBLIC WORKS SUPPLY CO.

DISTRIBUTORS OF

"DARLING" Fire Hydrants, Valves, Tapping Sleeves.
"DRESSER" Couplings, Sleeves, Clamps.
"FORD" Meter Test Benches, Yokes, Copper Horns.
"J-M" Bacteria free Asbestos Yarning Rope—Style 4210 and 4211.

CAST IRON GATE AND CURB BOXES

93-95 BROOKLINE ST., LYNN, MASS. Tel. LYnn 2-7823

Cement Lined Service Pipe

WE CAN NOW ship your requirements in all sizes of black or galvanized, steel or wrought iron pipe from stock. Genuine "Lipco" Cement Lined Pipe and Lead Lined Fittings have given and will continue to give years of trouble-free service.

CEMENT LINED PIPE COMPANY

93-95 Brookline St. Tel. LYnn 2-7823 Lynn, Mass.

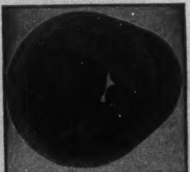
Pioneer Manufacturers of CENTRIFUGAL CEMENT LINED PIPES

Liquid Chlorine and Sodium Hypochlorite

Prompt deliveries from nearby plant at Berlin, N. H.

A PRODUCT OF QUALITY BROWN Company

Berlin, NEW HAMPSHIRE



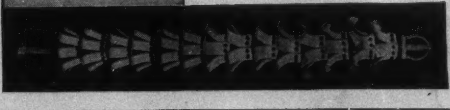
SALES or CONTRACT

R. F. BAHR

Get Full Service From Old Mains

The most practical way to meet today's overload demand is to clean clogged water mains. FLEXIBLE Pipe Cleaning Co., specializes in such jobs — any size — 2" to 72".

41 GREENWAY, HAMDEN, CONNECTICUT



New England Representative

Tel. SUDBURY 458 **P. O. BOX 153**

HILCO SUPPLY

delivers

A Complete Line of Waterworks Supplies To All New England

Quality Products — Fast, Courteous and Dependable Service

At the Junction of Routes 20 and 27
SOUTH SUDBURY, MASSACHUSETTS

Torrington Supply Company, Inc.

Water Works Distributors

MUELLER BRASS GOODS — STEEL PIPE
MUELLER TAPPING SLEEVES AND GATES — TOOLS
MUELLER HUB END VALVES — WATER PUMPS
COPPER TUBE AND BRASS PIPE

125 Maple Street, Waterbury, Connecticut
Telephone — PLaza 6-3641

Call MY STIC 8 — 9023 . . .

KENNEDY
K V
WALWORTH
HAYS
SMITH BLAIR INC
Dresser

for
PIPE
VALVES
FITTINGS
up to
24 inches in stock

Flanged pipe specials up to 20″ made in our own shop.

UTILITIES SUPPLY CORP.
425 RIVERSIDE AVENUE MEDFORD, MASS.

CLASSIFIED DIRECTORY OF ADVERTISEMENTS

ASBESTOS-CEMENT PIPE.	
Johns-Manville	viii
Keasbey & Mattison Company	v
BRASS GOODS.	
Caldwell Co., George A.	iv
Eureka Cement Lined Pipe Co.	xiv
Hilco Supply	xix
Mueller Co.	Following front cover
Pierce-Perry Co.	iii
Torrington Supply Co., Inc.	xx
Utilities Supply Corp.	xx
CALKING MACHINERY AND TOOLS.	
Hydraulic Development Corp.	vii
Mueller Co.	Following front cover
CAST IRON PIPE. (See Pipe, Cast Iron.)	
CEMENT LINED PIPE. (See Pipe, Cement Lined.)	
CHEMICAL FEED APPARATUS.	
B-I-F Industries	Following front cover
Wallace & Tiernan Co., Inc.	xi
CHLORINATORS.	
B-I-F Industries	Following front cover
Wallace & Tiernan Co., Inc.	xi
CLARIFIERS.	
Mills Engineering Co., Inc.	xiv
CLEANING WATER MAINS.	
Flexible Pipe Cleaning Co.	xviii
National Water Main Cleaning Co.	x
COCKS, CURBS AND CORPORATIONS.	
Caldwell Co., George A.	iv
Eureka Cement Lined Pipe Co.	xiv
Hays Mfg. Co.	xiii
Mueller Co.	Following front cover
Pierce-Perry Co.	iii
Utilities Supply Corp.	xx
CONCRETE PIPE. (See Pipe, Concrete.)	
CONTRACTORS' EQUIPMENT.	
Hydraulic Development Corp.	vii
CONTRACTORS.	
Layne-New York Co., Inc.	iii
Maher, D. L. Co.	iii
White Construction Co., R. H.	xiv
COUPLINGS, FLEXIBLE PIPE.	
Caldwell Co., George A.	iv
Public Works Supply Company	xviii
CURB BOXES.	
Bingham & Taylor Corp.	Following front cover
Caldwell Co., George A.	iv
Eureka Cement Lined Pipe Co.	xiv
Hays Mfg. Co.	xiii
Hilco Supply	xix
Mueller Co.	Following front cover
Pierce-Perry Co.	iii
H. R. Prescott & Sons, Inc.	xvi
Public Works Supply Company	xviii
Utilities Supply Corp.	xx
DIAPHRAGMS, PUMPS.	
Joseph G. Pollard Co.	Following front cover
% Proportioneers, Inc. % (B-I-F Industries, Inc.)	Following front cover
EJECTOR, PNEUMATIC.	
Mills Engineering Co., Inc.	xiv
ENGINEERS.	
Camp, Dresser & McKee	ii
Coffin & Richardson	ii
Crosby, Irving B.	ii
Fay, Spofford and Thorndike	ii
Haley and Ward	ii
Hazen and Sawyer	iii
Knowles Morris, Inc.	ii
Leggette, Brashears & Graham	ii
Maguire & Associates, Charles A.	iii
Metcalf and Eddy	ii
Pirnie Engineers, Malcolm	iii
Pitometer Associates, Inc., The	iii
Weston and Sampson	iii
Whitman and Howard	iii
ENGINES. (See Pumps and Pumping Engines.)	
EQUIPMENT. (See Contractors' Equipment.)	

CLASSIFIED DIRECTORY OF ADVERTISEMENTS *(Continued)*

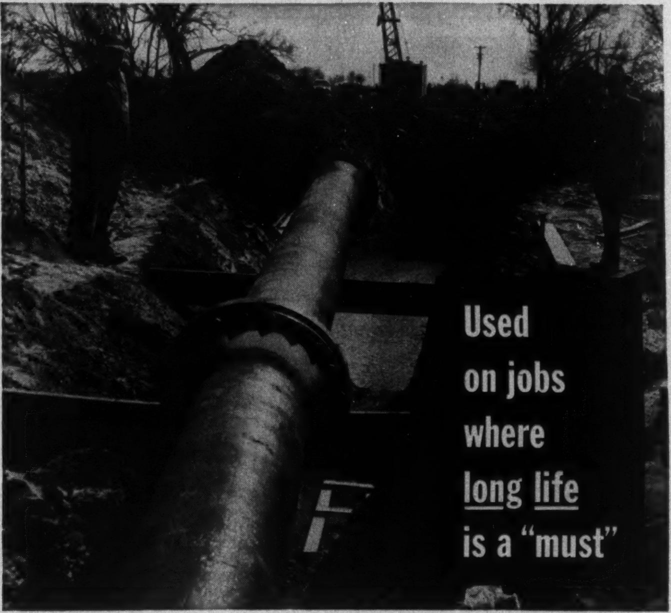
FEED WATER FILTERS.	
% Proportioneers, Inc. % (B-I-F Industries, Inc.)	Following front cover
Ross Valve Mfg. Co., Inc.	xvii
FILTRATION PLANT EQUIPMENT.	
B-I-F Industries	Following front cover
Mills Engineering Co., Inc.	xiv
FLAP VALVES.	
Eddy Valve Co.	xii
FLEXIBLE JOINTS.	
U. S. Pipe and Foundry Co.	xxvi
FURNACES.	
Hilco Supply	xix
Hydraulic Development Corp.	vii
Leadite Co., The	Back cover
Mueller Co.	Following front cover
Pollard Co., Joseph G.	Following front cover
H. R. Prescott & Sons, Inc.	xvi
Public Works Supply Company	xviii
Utilities Supply Corp.	xx
GATE VALVES. (See Valves.)	
GEARS.	
Mills Engineering Co., Inc.	xiv
GUNITE CONSTRUCTION.	
Gunite-Restoration Co., Inc.	ii
HOSE, SUCTION AND CONDUCTION.	
H. R. Prescott & Sons, Inc.	xvi
HYDRANTS, FIRE.	
Caldwell Co., George A.	iv
Eddy Valve Co.	xii
Hilco Supply	xix
Kennedy Valve Mfg. Co.	xv
Ludlow Valve Mfg. Co.	Following front cover
Mueller Co.	Following front cover
H. R. Prescott & Sons, Inc.	xvi
Public Works Supply Company	xviii
Rensselaer Valve Co.	Following front cover
Smith Mfg. Co., The A. P.	Following front cover
Utilities Supply Corp.	xx
Wood, R. D., Co.	Following front cover
HYDRANTS, PUMPS.	
Hilco Supply	xix
Joseph G. Pollard Co.	Following front cover
H. R. Prescott & Sons, Inc.	xvi
LEAD PIPE. (See Pipe, Lead.)	
LIQUID CHLORINE.	
Brown Co.	xviii
METERS, OIL AND WATER.	
Badger Meter Mfg. Co.	Following front cover
B-I-F Industries	Following front cover
Hersey Mfg. Co.	ix
Neptune Meter Co.	Following front cover
Pipe Founders Sales Corp.	xiv
Pittsburgh Equitable Meter Div.	Following front cover
Worthington-Gamon Meter Div.	vi
METER COUPLINGS.	
Badger Meter Mfg. Co.	Following front cover
Caldwell Co., George A.	iv
Ford Meter Box Co.	Following front cover
Hays Mfg. Co.	xiii
Hersey Mfg. Co.	ix
Mueller Co.	Following front cover
Neptune Meter Co.	Following front cover
Public Works Supply Company	xviii
Worthington-Gamon Meter Div.	vi
METERS (Venturi Type.)	
B-I-F Industries	Following front cover
METER BOXES.	
Bingham & Taylor Corp.	Following front cover
Ford Meter Box Co.	Following front cover
Mueller Co.	Following front cover
Public Works Supply Company	xviii
METER TESTERS.	
Badger Meter Mfg. Co.	Following front cover
Ford Meter Box Co.	Following front cover
Mueller Co.	Following front cover
Neptune Meter Co.	Following front cover
Public Works Supply Company	xviii
OIL ENGINES.	
Fairbanks, Morse & Co.	Following front cover
PIPE, ASBESTOS-CEMENT.	
Johns-Manville	viii
Keasbey & Mattison Company	v

CLASSIFIED DIRECTORY OF ADVERTISEMENTS *(Continued)*

PIPE, BRASS.	
Caldwell Co., George A.	iv
Hilco Supply	xix
Pierce-Perry Co.	iii
H. R. Prescott & Sons, Inc.	xvi
Torrington Supply Co., Inc.	xx
Utilities Supply Corp.	xx
PIPE, CAST IRON (and Fittings.)	
B-I-F Industries	Following front cover
Bingham & Taylor Corp.	Following front cover
Cast Iron Pipe Research Association	xxv
Hilco Supply	xix
Pipe Founders Sales Corp.	xiv
H. R. Prescott & Sons, Inc.	xvi
U. S. Pipe and Foundry Co.	xxvi
Utilities Supply Corp.	xx
Wood, R. D., Co.	Following front cover
PIPE, CEMENT LINED.	
Cast Iron Pipe Research Association	xxv
Cement Lined Pipe Co.	xviii
Eureka Cement Lined Pipe Co.	xiv
Pipe Founders Sales Corp.	xiv
U. S. Pipe and Foundry Co.	xxvi
Utilities Supply Corp.	xx
PIPE, COATING AND LININGS.	
Centriline Corp.	Following front cover
PIPE, CONCRETE.	
Lock Joint Pipe Co.	Facing front cover
PIPE CUTTING MACHINES.	
Caldwell Co., George A.	iv
Pollard Co., Joseph G.	Following front cover
Smith Mfg. Co., The A. P.	Following front cover
PIPE JOINTING MATERIAL.	
Caldwell Co., George A.	iv
Hilco Supply	xix
Hydraulic Development Corp.	vii
Leadite Co., The	Back cover
Utilities Supply Corp.	xx
PIPE, LEAD.	
Pierce-Perry Co.	iii
PIPE LINING.	
Cement Lined Pipe Co.	xviii
Centriline Corp.	Following front cover
PIPE, PRESTRESSED CONCRETE.	
Lock Joint Pipe Co.	Facing front cover
PIPE, WROUGHT IRON AND STEEL.	
Pierce-Perry Co.	iii
Torrington Supply Co., Inc.	xx
PLUG VALVES.	
Eddy Valve Co.	xii
Hays Mfg. Co.	xiii
Mueller Co.	Following front cover
Pittsburgh Equitable Meter Div.	Following front cover
PITOMETERS.	
Pitometer Associates, Inc., The	iii
PORTABLE AIR COMPRESSORS. (See Air Compressors.)	
PRESSURE REGULATORS.	
Hilco Supply	xix
Mueller Co.	Following front cover
Pittsburgh Equitable Meter Div.	Following front cover
H. R. Prescott & Sons, Inc.	xvi
Ross Valve Mfg. Co., Inc.	xvii
PROVERS, WATER.	
Badger Meter Mfg. Co.	Following front cover
Ford Meter Box Co.	Following front cover
PUMPS AND PUMPING MACHINES.	
Fairbanks, Morse & Co.	Following front cover
Layne-New York Co., Inc.	iii
Hilco Supply	xix
Maher Co., D. L.	iii
Mills Engineering Co., Inc.	xiv
Joseph G. Pollard Co.	Following front cover
H. R. Prescott & Sons, Inc.	xvi
Ross Valve Mfg. Co., Inc.	xvii
Turbine Equipment Co.	Following front cover
White Construction Co., R. H.	xiv
RATE CONTROLLERS AND GAUGES.	
Badger Meter Mfg. Co.	Following front cover
B-I-F Industries	Following front cover
REDUCERS, SPEED.	
Mills Engineering Co., Inc.	xiv
SHEAR GATES.	
Eddy Valve Co.	xii
Mueller Co.	Following front cover

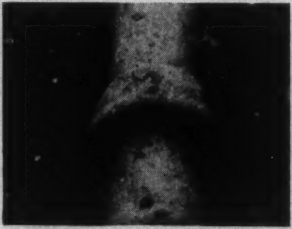
CLASSIFIED DIRECTORY OF ADVERTISEMENTS *(Continued)*

SLEEVES AND VALVE TAPPINGS.	
Caldwell Co., George A.	iv
Eddy Valve Co.	xii
Hilco Supply	xix
Ludlow Valve Mfg. Co.	Following front cover
Mueller Co.	Following front cover
H. R. Prescott & Sons, Inc.	xvi
Public Works Supply Company	xviii
Rensselaer Valve Co.	Following front cover
Smith Mfg. Co., The A. P.	Following front cover
Utilities Supply Corp.	xx
STEEL PLATE WORK.	
Pittsburgh-Des Moines Steel Co.	Following front cover
STRAINERS.	
Mills Engineering Co., Inc.	xiv
SUPPLIES AND TOOLS.	
Caldwell Co., George A.	iv
Hilco Supply	xix
Hydraulic Development Corp.	vii
Leadite Co., The	Back cover
Mueller Co.	Following front cover
Pierce-Perry Co.	iii
Pollard Co., Joseph G.	Following front cover
H. R. Prescott & Sons, Inc.	xvi
Public Works Supply Company	xviii
TAPPING MACHINES.	
Caldwell Co., George A.	iv
Hays Mfg. Co.	xiii
Mueller Co.	Following front cover
Smith Mfg. Co., The A. P.	Following front cover
TANKS, STEEL.	
Pittsburgh-Des Moines Steel Co.	Following front cover
TAPPING SLEEVES. (See Sleeves and Valves, Tappings.)	
VALVE BOXES.	
Bingham & Taylor Corp.	Following front cover
Caldwell Co., George A.	iv
Eddy Valve Co.	xii
Hilco Supply	xix
Kennedy Valve Mfg. Co.	xv
Mueller Co.	Following front cover
Pierce-Perry Co.	iii
Pipe Founders Sales Corp.	xiv
H. R. Prescott & Sons, Inc.	xvi
Public Works Supply Company	xviii
Smith Mfg. Co., The A. P.	Following front cover
Utilities Supply Corp.	xx
Wood, R. D., Co.	Following front cover
VALVE AND GATE GENERATORS.	
Mills Engineering Co., Inc.	xiv
VALVE INSERTING MACHINES.	
Mueller Co.	Following front cover
Smith Mfg. Co., The A. P.	Following front cover
VALVES, CHLORINE.	
Wallace & Tiernan Co., Inc.	xi
VALVES, GATE.	
Caldwell Co., George A.	iv
Eddy Valve Co.	xii
Hilco Supply	xix
Kennedy Valve Mfg. Co.	xv
Ludlow Valve Mfg. Co.	Following front cover
Mueller Co.	Following front cover
Pierce-Perry Co.	iii
H. R. Prescott & Sons, Inc.	xvi
Public Works Supply Company	xviii
Rensselaer Valve Co.	Following front cover
Smith Mfg. Co., The A. P.	Following front cover
Torrington Supply Co., Inc.	xx
Utilities Supply Corp.	xx
Wood, R. D., Co.	Following front cover
VALVES, REGULATING.	
Mueller Co.	Following front cover
Ross Valve Mfg. Co., Inc.	xvii
WASH FOUNTAINS.	
Mills Engineering Co., Inc.	xiv
WATER-PROOFING.	
Gunite Restoration Co., Inc.	ii
WATER WASTE DETECTION.	
Pitometer Associates, Inc., The	iii
WELLS, GRAVEL, FILTER AND DRIVEN.	
Layne-New York Co., Inc.	iii
Maher Co., D. L.	iii
WROUGHT IRON PIPE. (See Pipe, Wrought Iron and Steel.)	



Installing cast iron mechanical joint pipe across river at Salina, Kansas, for sewer main.

When an installation, once completed, should be as trouble-proof as planning and materials can make it—engineers rely on cast iron pipe. It has high beam-strength, compressive-strength and shock-strength. Its effective resistance to corrosion ensures long life, underground or underwater. These are reasons why cast iron pipe is so widely used for water lines in tough terrain, pressure and outfall sewers, river crossings, and encased piping in sewage treatment and water filtration plants. Cast Iron Pipe Research Association, Thos. F. Wolfe, Managing Director, 122 So. Michigan Ave., Chicago 3, Ill.



This 123-year-old cast iron water main is still in use in the distribution system of St. Louis, Mo.

®
CAST IRON

CAST IRON PIPE SERVES FOR CENTURIES

RADAR controlled and guided, high speed rockets streaking through the stratosphere may deliver New York mail to San Francisco in less than an hour!

100 years from now...

WE MAY SEND MAIL BY ROCKET!

A century from now a wonderful, exciting and different world. But there will be one familiar note. The cast iron pipe laid today will still be carrying water and gas to the homes and industries of tomorrow.

In over 60 American cities, these dependable cast iron water and gas mains, laid more than a century ago, are still serving efficiently. And modernized cast iron pipe, centrifugally cast, is even stronger, tougher, more durable.

U. S. Pipe is proud to be one of the leaders in a forward-looking industry whose service to the world is measured in centuries.

U.S.
PIPE
CAST IRON

U. S. PIPE AND FOUNDRY COMPANY, General Office: Birmingham 2, Alabama

A WHOLLY INTEGRATED PRODUCER FROM MINES AND BLAST FURNACES TO FINISHED PIPE.

The Journal of the New England Water Works Association

is a quarterly publication, containing the papers read at the meetings, together with reports of the discussions. Many of the contributions are from writers of the highest standing in their profession. It affords a convenient medium for the interchange of information and experience between the members, who are so widely separated as to find frequent meetings an impossibility. Its success has more than met the expectation of its projectors; there is a large and increasing demand for its issues, and every addition to its subscription list is a material aid in extending its field of usefulness.

All members of the Association receive the JOURNAL for three dollars per annum which sum is included in their annual dues; to all others the subscription is four dollars per annum.

TO ADVERTISERS

THE attention of parties dealing in goods used by Water Department is called to the JOURNAL OF THE NEW ENGLAND WATER WORKS ASSOCIATION as an advertising medium.

Its subscribers include the principal WATER WORKS ENGINEERS AND CONTRACTORS in the United States. The paid circulation is 1,200 COPIES.

Being filled with original matter of the greatest interest to Water Works officials it is PRESERVED and constantly REFERRED TO BY THEM, and advertisers are thus more certain to REACH BUYERS than by any other means.

The JOURNAL is not published as a means of revenue, advertising being inserted solely to help meet the large expense of publication.

ADVERTISING RATES

	One Issue	Four Issues
One Page	$ 48.00	$120.00
Half Page	30.00	75.00
Quarter Page	18.00	45.00
Eighth Page	11.00	27.00
One Page, 2 Colors	68.00	272.00
Back Cover	100.00	250.00
Cards, 1/10 Page	8.00	20.00

Size of page 4½ x 7½ net.

A sample copy will be sent on application.

For further information address the Advertising Agent

MRS. ALICE R. MELROSE,
73 TREMONT STREET,
BOSTON 8, MASSACHUSETTS

LEADITE

COSTS ARE REDUCED WHEN *LEADITE* IS USED

Of course, the greatest advantage in using LEADITE, is, that it makes a good, tight joint,—and thus reduces leakage to a minimum,—but LEADITE also offers the following advantages, which are worthy of serious consideration: Saves caulking expenses—Reduces cost of digging large bell-holes—Saves in cost of material—Reduces time required for pumping "wet trenches"—Saves time in preparation—Saves time in handling on the job—Saves in freight and hauling charges.

Another point, LEADITE saves "interest charges" by speeding up the completion of the water line.

The true value of LEADITE is best indicated by the fact that it has been used on THOUSANDS OF MILES of Water Mains,—all over this Country, as well as in many Overseas Countries.

The Pioneer self-caulking material for c. i. pipe,
Tested and used for over 40 years,
Saves at least 75%.

THE LEADITE COMPANY
Girard Trust Company Building — Philadelphia, Penna.

No Caulking